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Systems Engineering Management Plan NASA Traffic Aware Planner Integration into P-180 Airborne Test-Bed

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ACRONYMS

ADC	Air Data Computer
ADS-B	Automatic Dependent Surveillance – Broadcast
AID	Aircraft Interface Device
AOP	Autonomous Operations Planner
ASP	Airspace Systems Program (NASA)
ASRB	Airworthiness and Safety Review Board
ATC	Air Traffic Control
ATOL	Air Traffic Operations Lab – NASA Langley
CCU	Communications Convergence Unit
CITI	Collaborative Institutional Training Initiative
C of A	Certificate of Airworthiness
COM	Company Operations Manual
COO	Chief Operating Officer
COTS	Commercial-Off-The-Shelf
CTD	NextGen Concepts and Technology Development (NASA)
EFB	Electronic Flight Bag
EFIS	Electronic Flight Instrumentation System
EGPWS	Enhanced Ground Proximity Warning System
FDR	Flight Data Recorder
FL	Flight Level
FMS	Flight Management System
FSR	Flight Safety Release
FTE	Flight Test Engineer
FTOM	Flight Test Operations Manual
FTOSR	Flight Test Operations and Safety Report
FTRR	Flight Test Readiness Review
GFE	Government Furnished Equipment
HDU	High Speed Data Unit
HMI	Human-Machine Interface
ICA	Instructions for Continuing Airworthiness
ICAO	International Civil Aviation Organization
ICD	Interface Control Document
IFR	Instrument Flight Rules
INS	Inertial Navigation System
IPT	Integrated Product Team
IRB	Institutional Review Board
MEA	Minimum Enroute Altitude
MSL	Mean Sea Level
MTGW	Maximum Take-off Gross Weight
NAS	National Airspace System
NextGen	FAA Next Generation Air Transportation System

OPL	Operator Performance Laboratory – University of Iowa
OS	Operating System
PI	Principal Investigator
PIC	Pilot in Command
SEMP	Systems Engineering Management Plan
SMS	Safety Management System
SOW	Statement of Work
STC	Supplemental Type Certificate
SUA	Special Use Airspace
TAP	Traffic Aware Planner
TASAR	Traffic Aware Strategic Aircrew Requests
TCAS	Traffic (Alert and) Collision Avoidance System
TM	Technical Monitor (NASA)
TPM	Technical Performance Measure
TRL	Technology Readiness Level
TSO	Technical Standard Order
UAT	Universal Access Transceiver
WAAS	Wide Area Augmentation System
WBS	Work Breakdown Structure

1 OVERVIEW

This Systems Engineering Management Plan (SEMP) addresses the test-vehicle design, integration, and flight-testing for NASA's Traffic Aware Planner (TAP) software application. TAP is a three-dimensional aircraft trajectory optimizer developed to support NASA's Airspace Systems Program (ASP) and *NextGen Concepts and Technology Development* (CTD) projects. TAP uses a pattern-based genetic algorithm to generate flight path optimizations, based on own-state information combined with traffic, weather, and airspace boundary inputs obtained from external sources. TAP uses these data to offer aircrew vertical and lateral flight-path optimizations which can achieve significant fuel and time savings, while automatically avoiding traffic, weather, and restricted airspace conflicts. A sample TAP screen is shown in *Figure 1*.

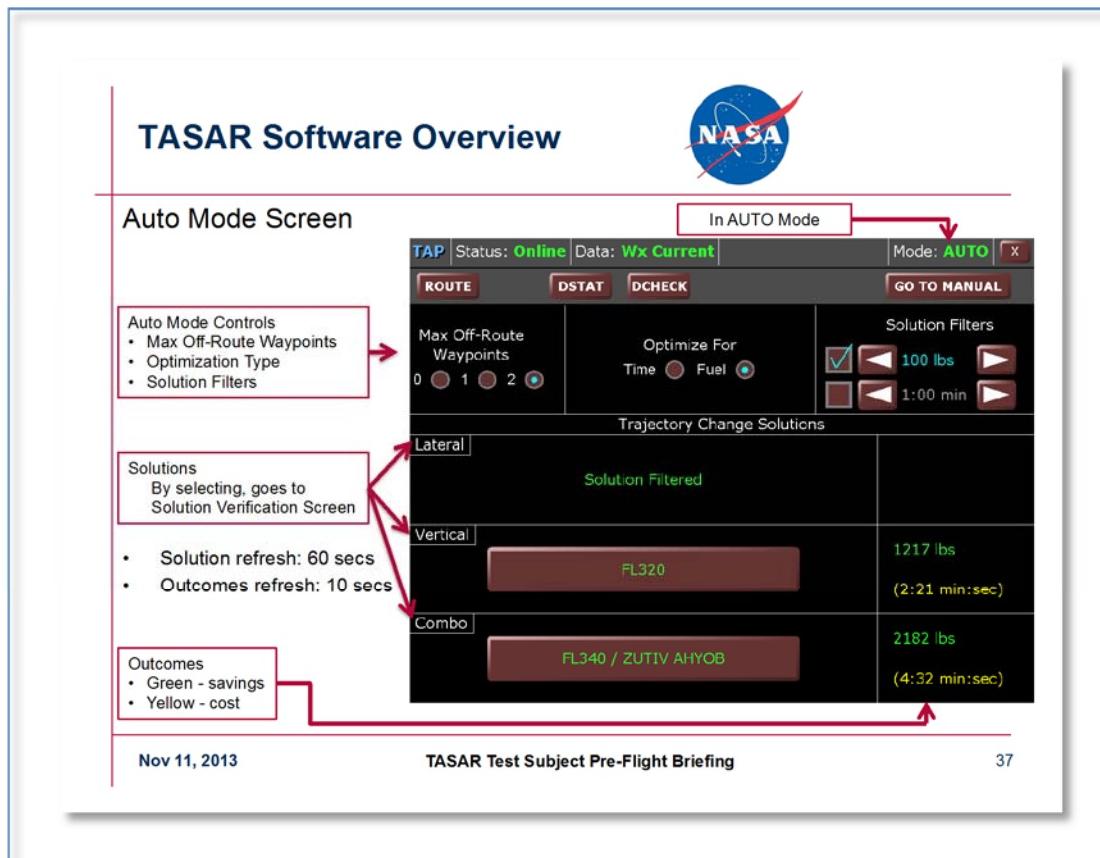


Figure 1. Sample TAP screen.

TAP's architecture and algorithms were derived from the NASA Autonomous Operations Planner (AOP) (Ballin, Sharma, Vivona, Johnson, & Ramiscal, 2002; Vivona, Karr, & Roscoe, 2013) incorporated in NASA Langley's Air Traffic Operations Laboratory (ATOL) (NASA,

2013). The flight-evaluation program entailed the migration of TAP from the simulator to an aircraft in order to validate its usability in a representative airborne environment. The program comprised three major activities: (1) development of the TAP application for Class 2 (portable) EFB applications (Federal Aviation Administration, 2012); (2) development and assessment of the TAP Human Machine Interface (HMI); and (3) assessment of TAP in a representative flight environment. This plan addresses the 24-month development program culminating in the TAP flight evaluations that were successfully concluded in November 2013.

TAP data sources include: Traffic Alert and Collision Avoidance System (TCAS) data; satellite broadband data; and Automatic Dependent Surveillance – Broadcast (ADS-B) traffic files. These capabilities are already available to a large cross-section of Air Transport and business aircraft that form the initial target market for TAP. The Federal Aviation Administration (FAA) has mandated ADS-B Out installation on most aircraft operating in U.S. airspace by January 1, 2020 as part of its Next Generation Air Transportation System (NextGen). TCAS is already broadly mandated by the International Civil Aviation Organization (ICAO) for installation in large (>13,000lb) transport aircraft, and an increasing number of aircraft already have installed broadband capability.

A key step in achieving the rapid operational deployment of TAP is the successful verification and validation of the system in a representative flight environment. This posed several challenges in the development program. Among the most significant was the requirement to port the foundational Autonomous Operations Planner (AOP) software from its original embedded-avionics simulator-based origins to an embedded avionics environment on the flight deck, hosted on an Electronic Flight Bag (EFB) platform. Considerable attention must also be paid to the selection and modification of a suitable flight-test platform that will maximize the long-term potential for the operational deployment of TAP, while minimizing immediate program risks. The systems engineering approach used to achieve these objectives is outlined in this document.

1.1 Scope

This SEMP relates to the integration of the TAP software into a suitably modified Piaggio P180 Avanti test platform (S/N 1037) for the purposes of evaluating TAP; it does not address the TAP software development process, except for the integration aspects. The SEMP captures the essence of the extensive systems engineering planning activities that went into the program, but it is not strictly a plan, because the TAP flight trials were successfully completed in November 2013. Most of the following sections reflect completed process, with known outcomes to the decisions that were taken over the past two years.

1.2 Limitations

Advanced Aerospace Solutions, LLC. (“AdvAero”) conducted the TAP integration and testing as a subcontractor to Engility Corporation, NASA’s prime contractor for the program. Because of these relationships, much of the material is confidential in nature and cannot be freely reproduced within this document. This material only addresses a small subset of the program technical documentation, but sufficient information has been included wherever possible to facilitate a good understanding of the system engineering process that were used.

2 APPLICABLE DOCUMENTS

The latest revisions of the following documents apply:

2.1 Supporting Project Documents

- A. ADV-TASAR-DEL-005 *Flight-Demonstration Aircraft Modification Plan*, Initial Issue, May 17, 2012.
- B. Marinvent Corporation *Flight Test Operations Manual (FTOM)*, Rev 1 August 12, 2011.
- C. Marinvent Corporation STC SA 05-104 *Honeywell Epic Control Display System Installation Piaggio P180 Avanti C-GJMM / 1037* Issue No. 1 dated November 02, 2005.
- D. Marinvent Corporation STC O-LSA12-151/D *Str. Prov. GPS Antenna & Miscellaneous Equipment Installation*, Issue No. 1 dated October 19, 2012.
- E. Marinvent Corporation STC O-LSA12-171/D *EMS Aviation Aspire Satcom System Installation*, Issue No. 1 dated October 24, 2012.
- F. Marinvent Corporation STC O-LSA12-172/D *NASA TASAR Program Provisions*, Issue No. 1 dated October 22, 2012.
- G. NASA LaRC *Minutes of May 10, 2012 Meeting of the Airworthiness and Safety Review Board (ASRB)* dated May 15, 2012.
- H. NNL12AA06C, *Traffic Aware Strategic Aircrew Requests (TASAR) Traffic Aware Planner (TAP) Interface Control Document (ICD)*, Version 1.8, January 22, 2013.
- I. NNL12AA06C, *Initial Analysis of Operational Use Cases and Methodologies*, Jeff Henderson (Engility Corporation), May 31, 2012w.
- J. NNL12AA06C DEL 7 *NASA & FAA Flight-Trial Approval Requirements*, Initial Issue, June 30, 2012.
- K. NNL12AA06C, *Statement of Work for Traffic Aware Strategic Aircrew Requests (TASAR) Analysis and Development*, as approved.
- L. NNL12AA06C, *TASAR Flight-Trial Hazard Analysis*, v1.0 Nov 9, 2012.

- M. NNL12AA06C DEL 11, *TASAR Flight Trial Research Plan*, Draft V1.0, Dec 21, 2012.
- N. NNL12AA06C FTOSR DEL-19, *Traffic Aware Strategic AircREW Request Flight Test Operations and Safety Report*. Version 1.3 August 13, 2013.
- O. NNL12AA06C *TASAR Flight Trial Test Plan*, v1.0 Dec 21, 2012.
- P. *SkyService SMS Manual*, No. 23, Issue 2, CAR 573, November 15, 2012.

2.2 Government / Regulatory Documents

- Q. 14 CFR Part 1230, *Protection of Human Subjects*, June 18, 1991 or later edition.
- R. LMS-CP-0904, *Authorizing Flight Aboard Non-LaRC Aircraft*, Rev C, July 26, 2012.
- S. LMS-OP-7831 NASA Langley, *Conducting Research Activities in the Research Directorate (RD)*, Rev A: RD.
- T. LPR 7100.10 NASA Langley Procedural Requirements *Protection of Human Research Subjects*, October 29, 2010.
- U. NASA DOP-0-300, *Aircrew Flight Operations Manual*, Revision 1, Expires October 22, 2015.
- V. NPD 7100.8E NASA Policy Directive *Protection of Human Research Subjects* (Revalidated with admin. changes 6/14/2007): May 31, 2002.
- W. NPD 7900.4C NASA Policy Directive, *NASA Aircraft Operations Management*, April 08, 2009.
- X. NPR 7100.1 NASA Procedural Requirements, *Protection of Human Research Subjects* (Revalidated 7/7/08), effective date: March 28, 2003.
- Y. NPR 7900.3C NASA Procedural Requirements, *Aircraft Operations Management Manual*, July 15, 2011.

2.3 Industry Reference Documents

- Z. ARINC 424 *Navigation System Data Base Standard*, ARINC, Inc.
- AA. ARINC 429 *Digital Information Transfer System*, ARINC, Inc.
- BB. ARINC 834 Aircraft Data Interface Function (ADIF) standard, ARINC, Inc.
- CC. RTCA-DO-160G *Environmental Conditions and Test Procedures for Airborne Equipment*. 12/08/2010. RTCA, Inc.
- DD. Federal Aviation Administration AC 23.1309-1E *System safety analysis and assessment for part 23 airplanes*, 2011.
- EE. RTCA-DO-178C *Software Considerations in Airborne Systems and Equipment Certification*. 12/13/2011. RTCA, Inc.

- FF. RTCA-DO-254 *Design Assurance Guidance for Airborne Electronic Hardware*. 4/19/00. RTCA, Inc.
- GG. RTCA DO-260B *Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B)*, 12/13/2011. RTCA Inc.
- HH. SAE ARP 4754. Guidelines for development of civil aircraft and systems. (Rev A ed.) SAE International. 2010.

3 GENERAL DESCRIPTION OF SYSTEM ARCHITECTURE

The TAP test system architecture derives from the fundamental requirement of integrating the TAP software into the airborne test vehicle. TAP is a Windows™ application which is hosted on a suitable EFB, laptop, or PC computer that is in turn interfaced to aircraft data sources for own-state, ADS–B, TCAS, and broadband connectivity. Multiple instantiations of the TAP software may be hosted simultaneously on different computer platforms via wired (Ethernet) or wireless (Wi-Fi) connectivity. The test system architecture comprises the following principal elements as shown in *Figure 2*.

1. The airborne test-platform, including instrumentation and data sub-systems;
2. ADS-B/TCAS sub-system;
3. Broadband sub-system;
4. Aircraft Interface Device (AID) sub-system, responsible for the interface between the TAP software and the aircraft data systems;
5. PC, EFB, and laptop computer sub-systems; and
6. The TAP software.

The relationship between these elements is shown in *Figure 2* below.

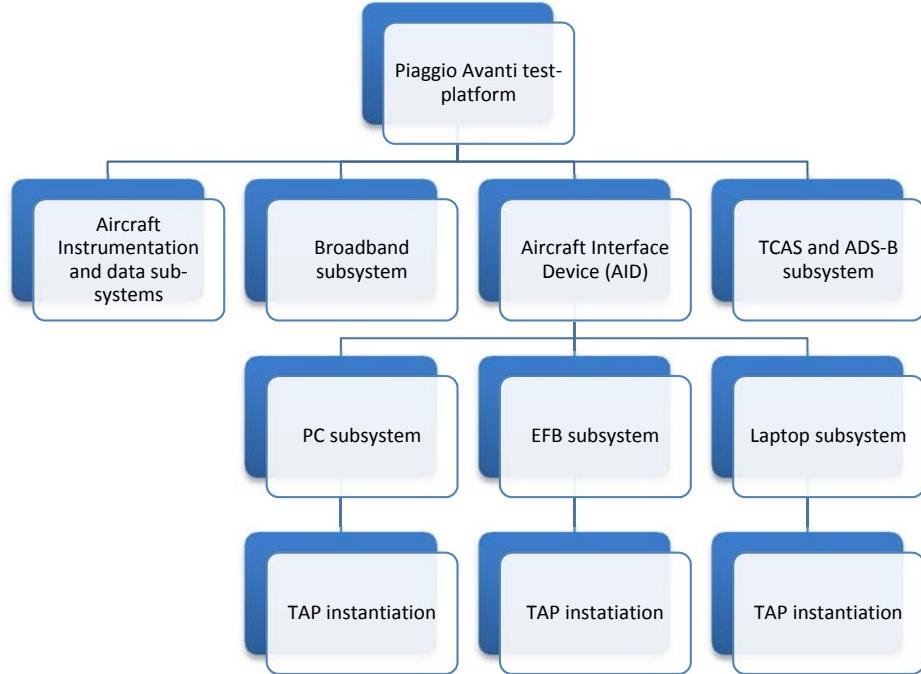


Figure 2. Test-platform system architecture.

4 SYSTEM ENGINEERING PROCESS

A rapid-prototyping research paradigm was adopted for the TAP flight test program. This required a degree of modification to Blanchard's (2008) classical "top down, integrated, life-cycle approach to system design and development." Four principal factors imposed severe systems engineering challenges that necessitated a novel approach to the design process:

1. The FAA has yet to fully-define the ADS-B In system requirements that are key to TAP functionality, and there is no timetable for an ADS-B In regulatory mandate. The principal means of communicating ADS-B data to TAP was therefore not fully defined before the system was subjected to a formal flight trial.
2. As indicated in the introduction, TAP's architecture and algorithms were derived from NASA's AOP software that has never been deployed in an airborne environment.
3. Because of the very demanding schedule, development of the TAP software was conducted in parallel with the development of the airborne test-bed. This posed particular challenges because the two programs were completely co-dependent, yet there was no outside framework of top-level system requirements (technical or regulatory) to help guide and harmonize these parallel rapid-prototyping development processes.

4. The 24-month development schedule from the formation of the Integrated Product Team (IPT) to the conduct of the flight trials was extremely compressed, particularly in light of the parallel development of the software and the test vehicle.
5. As discussed in section 5.1 below, a primary objective of the program was to facilitate the rapid commercial deployment of the TAP while minimizing changes to existing avionics architectures or displays for near-term forward-fit applications. This objective imposed conflicting demands of implementing a Technology Readiness Level (TRL) 9 “production ready” integration solution using TRL 4 (laboratory) software.

4.1 System Operational Requirements

The TAP program was governed by three sets of operational requirements: (1) TAP software functionality requirements, which dictated the capabilities of the software as installed; (2) Strategic flight trial requirements, which transcended the performance of the system and imposed significant additional data requirements; and (3) commercialization technical requirements, which had a major influence on the TAP implementation options in the test vehicle.

4.1.1 TAP software functionality requirements

This SEMP does not address the TAP software functionality in detail, as the software is Government Furnished Equipment (GFE), delivered “as is.” The data inputs required by the software did, however, define important system interfaces with the EFB hardware system and the test-bed systems, as discussed in section 4.4.

4.1.2 Flight trial requirements

The TAP Statement of Work (SOW) (Project document reference K) includes the following flight trial objectives:

1. Identification of operational factors unique to the in-flight environment that may affect TAP functionality, its data requirements, HMI, and operating procedures.
2. Development of pilot procedures that are compatible with realistic hardware and procedural environments for TAP commercial deployment.
3. Promotion of readiness for further simulation experiments and flight evaluations geared towards making TASAR operations available to the aviation community (avionics developers, aircraft operators, and regulatory officials) for near-term operational use.

4.1.3 Commercialization technical requirements

NASA requires the TAP system to impose the minimum feasible changes to the existing avionics architectures and displays for near-term forward-fit applications on Air Carrier aircraft.

This objective severely limits the system architectures that can be adopted for the test vehicle, essentially eliminating any “breadboard” or “orange wire” (experimental) implementations, because these would not be deployable as end-customer solutions. This entailed the maximum use of FAA certified Commercial-off-the-shelf (COTS) hardware, as discussed in section 4.6.

4.2 Maintenance Concept

All equipment installed as part of the TAP test program will be certified in accordance with the Federal Aviation Regulations (FARs). Explicit Instructions for Continuing Airworthiness (ICA) were a necessary part of such approvals. The ICAs listed majority of the equipment installed for TAP as subject to on-condition maintenance. The few life-limited items are tracked electronically using Avtrak® software, along with all of the life-limited systems and components in the aircraft.

4.3 Technical Performance Measures (TPMs)

Two classes of TPMs applied to the TAP flight test program: (1) TAP system performance measures; and (2) regulatory performance measures required for certification of the TAP installation and approval for the conduct of the flight trials. The TAP system TPMs for the flight trials were very straightforward: the single criterion was the successful functioning of TAP, defined by the provision of meaningful trajectory optimizations, while operating in the National Airspace System (NAS). Although it would have been possible to define more granular TPMs, such as successful Automatic and Manual mode TAP operation, this was not deemed necessary, because any successful TAP advisory would indicate that the entire system integration activity had been successful. The formal test planning documents included detailed evaluations of every TAP mode and function, but these were not success criteria for the test.

Three forms of regulatory approval applied the TAP installation: (1) Airworthiness certification by the regulatory authorities; (2) FAA operational approval for flight in the NAS; and (3) NASA approval for the conduct of the experiment. All of these approvals were accomplished in accordance with the applicable regulatory and guidance documents, and detailed compliance plans were developed for each. The airworthiness approvals for the ADS-B system contained extensive TPMs as defined in RTCA DO-260B (Reference GG). All installed avionics were additionally certified to meet the extensive TPMs specified in:

1. *DO-160G Environmental Conditions and Test Procedures for Airborne Equipment*
(Reference CC)
2. *FAA AC 23.1309-1E System safety analysis and assessment for part 23 airplanes*
(Reference DD)

3. DO-178C *Software Considerations in Airborne Systems and Equipment Certification* (Reference EE)
4. RTCA-DO-254 *Design Assurance Guidance for Airborne Electronic Hardware* (Reference FF)
5. SAE ARP 4754. *Guidelines for development of civil aircraft and systems* (Reference HH)

4.4 Functional Analysis

The top-level functional requirements for TAP flow from the Concept of Operations:

(TAP) offers onboard automation for the purpose of advising the pilot of traffic compatible trajectory changes that would be beneficial to the flight. The TAP onboard automation is expected to be hosted on a Class 2 Electronic Flight Bag (EFB) and leverages ADS-B surveillance information to increase the likelihood of ATC approval of pilot-initiated trajectory change requests, thereby increasing the portion of the flight flown on or near a desired business trajectory. All automation and pilot procedures are fully dedicated to a single aircraft which allows tailoring of optimization criteria to the specific objectives of each flight and provides for timely responses to changing situations (Henderson, 2013).

4.4.1 TAP Use Cases

The following Use Cases were derived from the Concept of Use. TAP will support three types of optimization maneuvers, in both automatic and manual modes, as shown in the following table.

Table 1.
TAP Operational Scenarios

Optimization	Trajectory Change Options
Lateral	<ol style="list-style-type: none"> 1. Direct to downstream waypoint 2. Change one or two waypoints along route then reconnect to route upstream of arrival fix
Vertical	<ul style="list-style-type: none"> • Climb or descend to another altitude
Combined Lateral & Vertical	<ol style="list-style-type: none"> 1. Direct to downstream waypoint 2. Change one or two waypoints along route then reconnect to route upstream of arrival fix 3. Climb or descend to another altitude

Note. Adapted from NNL12AA06C (Project Reference N).

Further details of the TAP test scenarios appear in section 4.7.

4.4.2 TAP functional requirements

TAP requires following logical interfaces to be supported by the test vehicle architecture:

1. Comprehensive own-aircraft state information;
2. ADS-B and TCAS traffic data;
3. Polygonized Special Use Airspace (SUA) data;
4. Third-party flight tracking data;
5. Wind-field data; and
6. Broadband Internet access.

4.5 Requirement Allocation

The existing aircraft architecture determines the allocation of the TAP functions to the individual test-bed sub-systems as shown in Table 2.

Table 2.
TAP Functional Allocation

TAP Function, sub-function	System allocation	Interface Type
1 Own-aircraft state		
1.1 Air Data (altitude, airspeed, etc.)	#1 Air Data Computer (ADC) via Aircraft Interface Device (AID)	ARINC 429
1.2 Navigation data	#1 Flight Management System (FMS) via AID #1 GPS	ARINC 429 ARINC 429
1.3 Flight plan data	#1 FMS via AID	ARINC 429
1.4 Waypoint geo data	TAP internal	ARINC 424
1.5 Autopilot data	Flight Data Recorder (FDR) Bus via AID	ARINC 429
2 ADS-B and TCAS traffic data	TCAS 3000 SP via AID	ARINC 429 per RTCA DO-260A
3 SUA data	Broadband via AID	Packed, proprietary
4 3 rd Party Flight Tracking Data	Broadband via AID	Provisions only
5 Wind-field data	Broadband via AID	Packed, proprietary
6 Broadband Internet	Iridium satellite sub system	Ethernet

Note. Adapted from ADV-TASAR-DEL-005 (Project reference A).

4.6 System Synthesis, Analysis, and Design Optimization

The decomposition of the allocated system functions into the architectural elements of the test vehicle was governed by two “hard” external constraints: the selected aircraft was required to retain its Normal Category Certificate of Airworthiness, and it also had to retain its certification for single-pilot operations. The former avoids numerous operational restrictions, including geographic and weather limitations and constrained passenger carriage; the latter removes

restrictions regarding who may occupy the copilot's seat, and also mitigates the use of uncertified software on the non-handling side of the cockpit. Design decisions regarding specific hardware requirements were based on the system functional allocations from Table 2, subject to these two constraints.

4.6.1 Test Vehicle

The test vehicle was the principal element of the system architecture, as it had to support all of the functionality required by TAP and its associated systems. In addition to supporting the TAP software functionality requirements, the test vehicle also supported the additional commercialization and flight trial requirements derived from section 4.1.

4.6.1.1 *Test vehicle top-level system requirements*

The test vehicle shall:

1. Accommodate the TAP software and all required internal and external interfaces defined in the TAP Interface Control Documents (ICD) (Program reference H).
2. Accommodate a full test crew of seven personnel, comprising: a safety pilot, a test-subject pilot, a test director, a flight test engineer, a data engineer, a TAP software specialist, and a NASA monitor or observer.
3. Have a broad flight envelope (speed and altitude) representative of the turbine business aircraft and Air Carrier target market for TAP. A cruise Mach number of 0.6 and a cruise altitude in excess of 36,000 feet were deemed representative based on focus group discussions.
4. Have adequate endurance at mid and high altitudes (10,000 – 36,000 feet) to support the planned flight durations of 2.5 – 3.0 hours, with legally required IFR reserves.
5. Be capable of day and night VFR (Visual Flight Rules) and IFR (Instrument Flight Rules) day and night operations in moderate icing conditions, to maximize mission flexibility and probability of success.
6. Be capable of performing all of the preceding under single-pilot operations, for the reasons already discussed.
7. Possess a Normal Category Certificate of Airworthiness (C of A), to avoid excessive test restrictions associated with Experimental flight permits.

4.6.1.2 *Test vehicle selection*

The AdvAero Piaggio P180 Avanti test-bed aircraft was selected as the TAP test platform. The Avanti is a very high performance turboprop pressurized all-weather twin powered

by two Pratt & Whitney PT6A-66 turboprops (2x 850 SHP). The aircraft has a very broad flight envelope with a cruise speed of approximately 375 KTAS (0.65M) at 28,000 ft. and a ceiling of 41,000 ft. at ISA. The fuel capacity of 2,900 lbs. yields a maximum endurance of approximately four hours, and a maximum range of approximately 1,200 NM. The aircraft is certified with a Normal Category Certificate of Airworthiness (C of A) for single pilot day/night/VFR/IFR operations in known icing conditions. The aircraft's payload of 1,560 lbs. allows for a test crew of seven, including two pilots, to be flown on most missions. The cabin is arranged with a flight test station behind the cockpits which seats two test personnel, and club seating for four additional test-crew in the aft cabin, as shown in *Figure 3* below. The Piaggio P180 Avanti is one of a very few aircraft that meet all of the operational requirements for the TASAR trials.

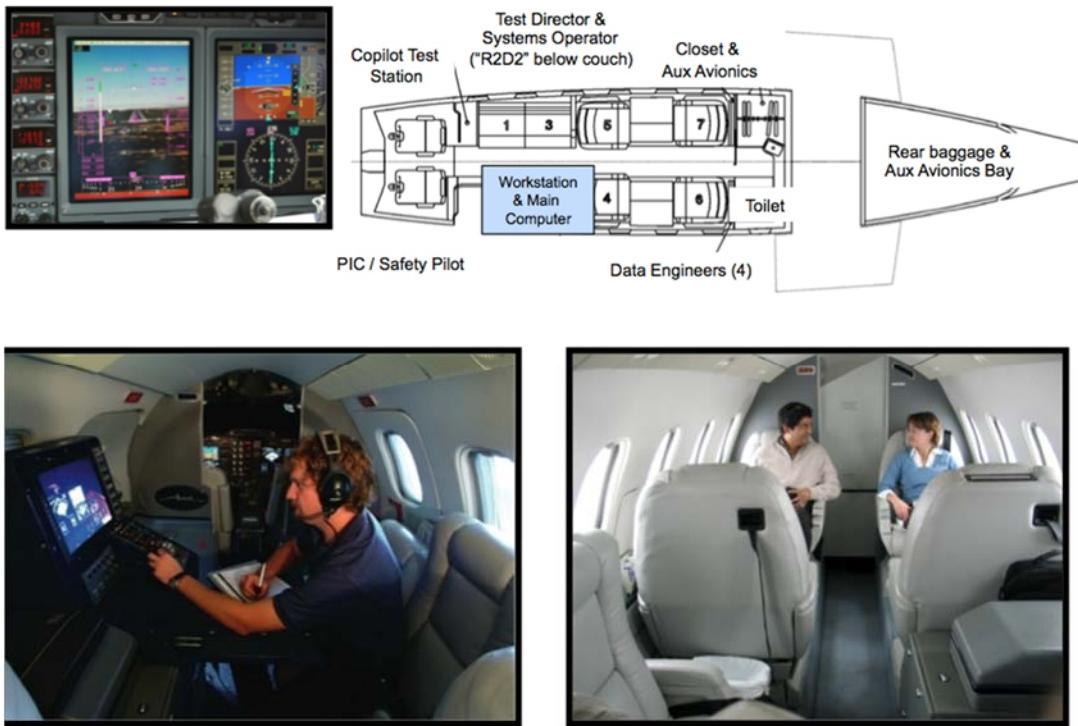


Figure 3. Test-vehicle flight test station and cabin.

4.6.2 EFB and ADS-B subsystems

The EFB and ADS-B systems are two closely integrated TAP components that were not part of the test-vehicle's baseline avionics suite. As previously discussed, the FAA has yet to fully-define the ADS-B-In system requirements, and there are very few commercially deployed and certified systems. The selected systems must therefore accommodate future growth via firmware upgrades to avoid a rapid obsolescence as the regulations mature. An additional factor for the ADS-B selection is the operating band. The two options are 1090 MHz Extended-squitter

(1090ES) and the 978 MHz Universal Access Transceiver (UAT). The UAT alternative has several advantages, including a less-congested frequency spectrum, but the system is prohibited for ADS-B Out operations above 18,000 ft., and is unusable outside the domestic USA, including Canada. Both these considerations could limit severely the downstream application of a UAT-based TAP system, despite its other benefits.

The EFB must support an FAA certified operating system (OS), to preclude having to change platforms should the FAA decide that the TAP intended functionality merits a certified installation in accordance with RTCA DO-178C (Program reference DD). For example, existing regulations already prohibit the airborne display of aircraft position using uncertified OSs, and might even preclude a graphical TAP user interface. These problems were mitigated from the outset by selecting an EFB with a certified OS option. The EFB, TCAS, and ADS-B subsystems also require demonstrated interoperability, in order to avoid significant schedule and technical risks associated with the integration of three complex dissimilar systems. Accordingly, the EFB and ADS-B requirements are as follows:

4.6.2.1 EFB and ADS-B subsystem requirements

The EFB system shall:

1. A Class 2 EFB shall be integrated with the test-vehicle and TAP software (the Class of EFB is a SOW constraint).
2. The EFB shall have sufficient processing power, memory, and display resolution, to support TAP in accordance with the TAP ICD (Program reference H).
3. The EFB shall have the option to host a certified OS.
4. The ADS-B system shall be compatible with the aircraft's existing avionics to avoid cost and schedule risks.
5. The ADS-B system shall support the 1090ES standard.
6. The ADS-B, EFB, and TCAS subsystems shall have demonstrated interoperability.
7. The ADS-B, EFB, and TCAS subsystems shall be certified for aviation applications.

4.6.2.2 EFB subsystem selection

Of all of the stated EFB requirements, the need for a certified OS governed, because only two COTS EFBs offered this option: the Astronautics NEXISTTM¹ and the Goodrich SmartDisplayTM. The NEXISTTM form factor is not suitable for the confined cockpit of the Piaggio Avanti, leaving the Goodrich solution as the only alternative (*Figure 4*). This unit includes the

¹ <http://tinyurl.com/7vktspg>

certified DEOS™ OS, which is suitable for all classes of EFB hardware and software types. The Goodrich SmartDisplay™ also supports the Windows XP® embedded OS, which will be used to host the TAP software if the DEOS certified option is not required.

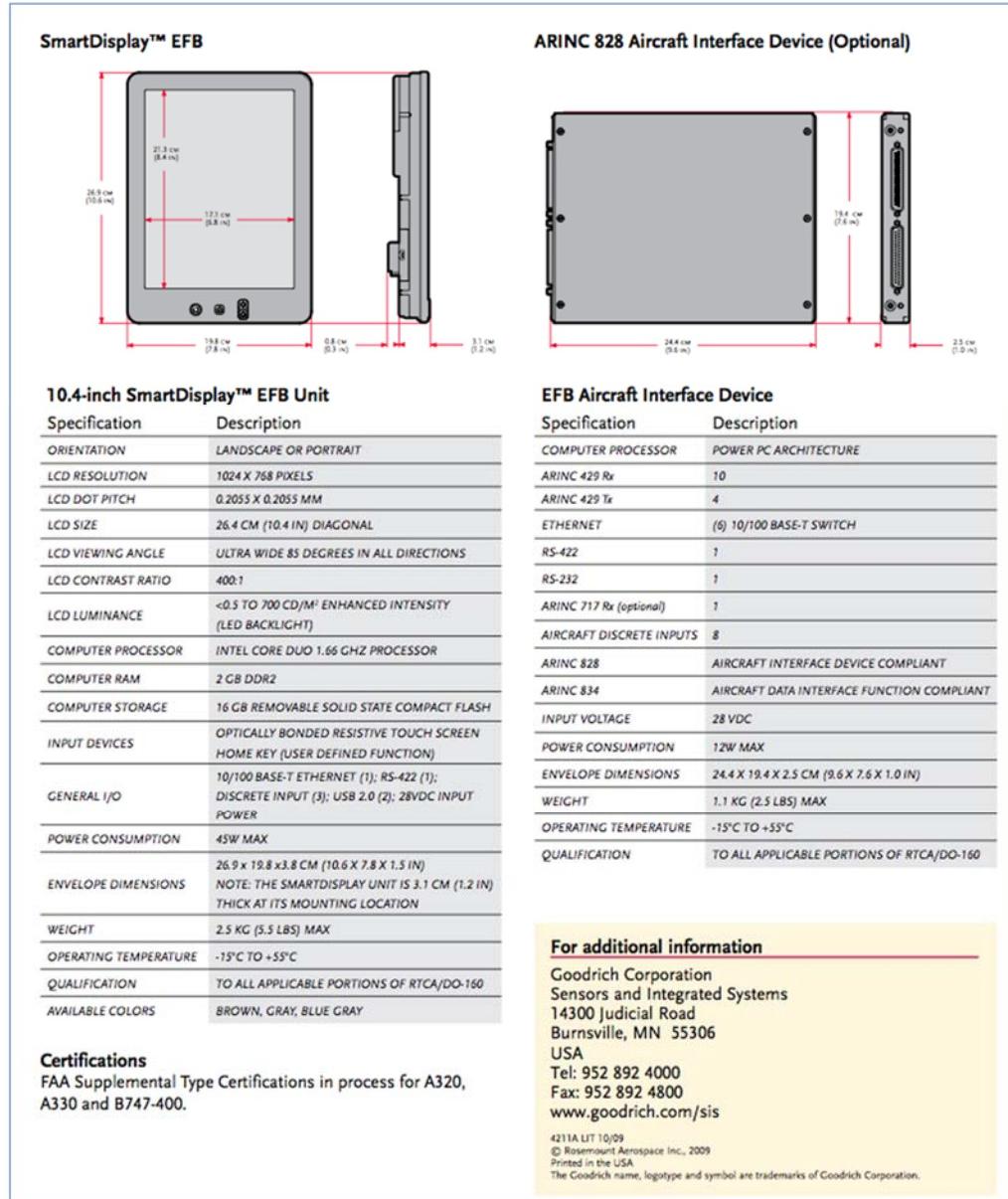


Figure 4. Goodrich SmartDisplay® EFB

4.6.2.3 ADS-B subsystem selection

The ACSS TCAS 3000SP² system (*Figure 5*) was selected to perform the TCAS and ADS-B functions for the following reasons:

² <http://www.acssdealeronline.com/prodTCAS300SP.aspx>

1. The system is a derivative of the aircraft's existing T2CAS system, which minimized the risks associated with performing and certifying the upgrade.
2. The TCAS 3000SP has demonstrated the required interoperability with the Goodrich SmartDisplay EFB: the combination hosts the commercially available SafeRoute™ application suite.
3. The TCAS 3000SP is a leading-edge design which supports firmware updates to accommodate new functionality as the ADS-B In standards continue to evolve.
4. The FAA has selected this unit for its test fleet at the W.J.H. Technical Centre, and the FAA has subsidized JetBlue Airlines \$4.2M to equip 35 Airbuses with this equipment.³ These factors may assist the future commercial deployment of TAP on similarly equipped aircraft.



Figure 5. ACSS TCAS 3000SP. © 2014 Advanced Aero Solutions, LLC. Reprinted with permission.

Trade names and trademarks are used in this report for identification only. Their usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

4.6.3 AID subsystem

The TASAR flight trials will require the integration and dissemination of data from numerous disparate sources (TCAS, ADS-B, Datalink, etc.). The commercialization

³ <http://tinyurl.com/6tsdspr>. "Avionics Today - JetBlue Announce Partnership Agreement for ADS-B Equipage."

requirements (section 4.1.3) precluded extensive custom wiring for these interfaces in customer aircraft because of cost and certification considerations. For this reason, a data concentrator approach was selected to handle all of the communications between the TAP platform and the aircraft. Data concentrators used in such applications are commonly referred to as Aircraft Interface Devices (AID), which is the nomenclature adopted for this program. The AID interfaces between the EFB and TAP to the following subsystems:

1. Dual Honeywell CDS/R Electronic Flight Instrument System (EFIS) IC-1080 display computers driving 8”x10” LCD displays;
2. Universal UNS1-EW FMS with LPV and RNP capability;
3. Honeywell Laseref V Micro Inertial Reference Unit;
4. Dual Honeywell AZ 950 micro-ADCs;
5. Collins APS-65 flight guidance computer and autopilot; and
6. The aircraft’s R2D2 and workstation computers (c.f. section 4.6.5 below).

4.6.3.1 AID requirements

The AID shall:

1. Accommodate the internal and external interfaces contained in the TAP software ICD (Program reference H), including:
 - a. Air Data (altitude, airspeed, etc.);
 - b. FMS Navigation data and flight plan data;
 - c. GPS position data;
 - d. Autopilot state;
 - e. ADS-B and TCAS traffic data; and
 - f. Broadband Internet connectivity.
2. Provide all required power and data interfaces to the EFBs that host the TAP application.
3. Use industry-standard data protocols to interface with EFB hardware to facilitate downstream installations.
4. Be certified for aviation applications.

4.6.3.2 AID selection

The Goodrich AID was selected for the following reasons:

1. It is a certified data concentrator that packages ARINC 429 data into a standard network protocol (TCP) for transmission over Ethernet, using the Simple Text Avionics Protocol (STAP) defined by the ARINC 834 “Aircraft Data Interface Function (ADIF)” standard.

2. The unit's physical interface is based on the ARINC 828 "EFB Standard Interface" standard for universal EFB connectors.

In summary, the combination of the ACSS TCAS 3000SP with the Goodrich SmartDisplay™ and AID is the only currently identified system that meets the TAP constraints, and which is suitable for installation in the Avanti test-bed aircraft. This combination has the advantages of a certified OS option, industry standard interfaces, and proven interoperability between the ADS-B and EFB components. These factors should significantly reduce program risk, and enhance the prospects of an early commercial deployment of the TASAR system. As an added benefit, the ACSS TCAS3000 is at the forefront of Air Carrier deployment for ADS-B operations, which will facilitate the eventual deployment of TAP to these customers.

4.6.4 Broadband subsystem

The broadband subsystem serves two functions: provision of specified data via Internet connectivity, and provision of distributed network services throughout the aircraft cabin for wireless TAP clients.

4.6.4.1 Broadband requirements

The broadband system shall:

1. Interface to a suitable terrestrial Internet source to support the TAP broadband data performance requirements defined in the TAP ICD (Program reference H).
2. Be of a form factor suitable for mounting on the test-bed aircraft, including antenna installations.
3. Provide a router function that supports a minimum of two wired and six wireless clients for the broadband data.
4. Be certified for aviation applications.

4.6.4.2 Broadband subsystem selection

Three currently available options offer the required broadband connectivity: Ku-band satellite, Inmarsat satellite, and cellular air-to-ground solutions. The Ku option is impractical for small aircraft such as the Avanti, and was therefore eliminated. Table 3 contrasts the Inmarsat Aspire® solution offered by Honeywell Aerospace with the GogGo® cellular alternative offered by Aircell.

Table 3.
Broadband Options Compared

Characteristic	Honeywell Aspire 200®	Aircell GoGo Biz ® ATG2000
Communication method	Inmarsat I-4 satellite network	Aircell air-ground cellular network
Antennas	One blade, top mounted	Two blades, bottom mounted
Usable altitude	All, including on ground	Geographically dependent, typically above 10,000 ft.
Bandwidth	200 kbps	Unpublished
Data content	Text only	Voice and text support
Wi-Fi WAN support	802.11 b/g Wi-Fi® access, up to 54 clients	No
Pricing	Comparable	Comparable

Note. Adapted from published on-line marketing materials

<http://aerospace.honeywell.com/en/products/communication-nav-and-surveillance/satellite-communications/terminal-products-inmarsat-l-band/aspire-200>
<http://aircell.com/services/gogo-biz/#ATG2000>

The Honeywell Aspire™ 200 SATCOM was selected primarily because the Avanti test-bed did not have sufficient space available to mount the twin bottom-mounted antennas used by the Aircell unit, due to other system installations. In addition, the GoGo would have required the addition of a router to support the wireless requirement, which would have added weight and complexity.

4.6.4.3 Broadband subsystem description

The Aspire system was installed and certified via three Canadian Supplemental Type Certificates (STC) that covered the antenna structural provisions and the system integration aspects (References D, E, and F). *Figure 6* shows a schematic of the Aspire 200, as installed.

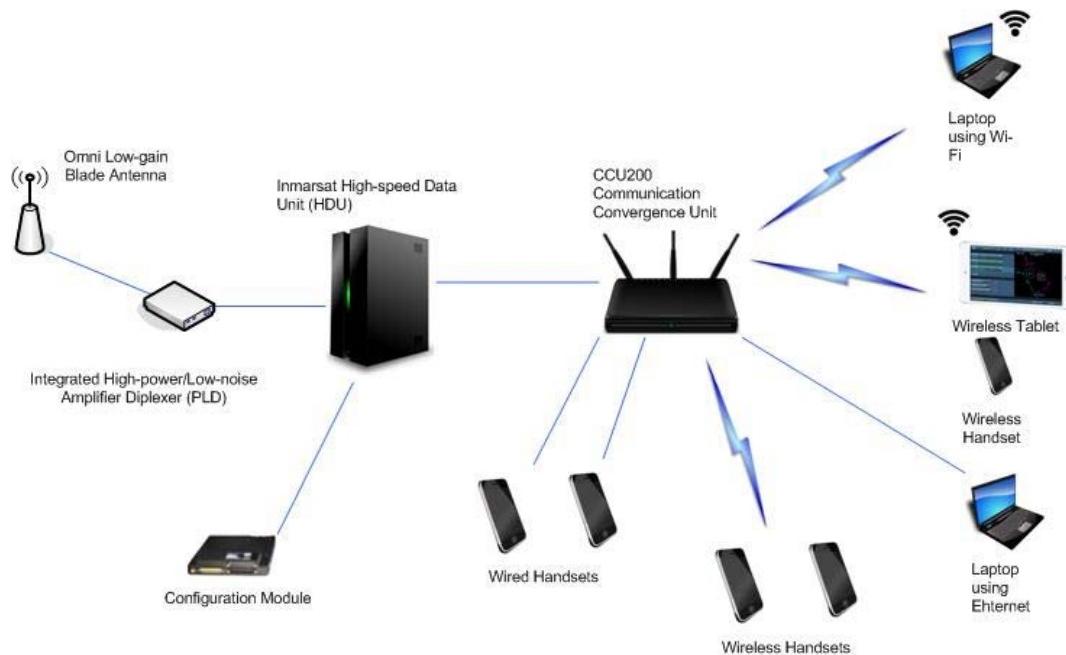


Figure 6. Generic representation of the Honeywell Aspire™ 200 architecture.

The CCU-200 is a full-service multi-port router and Wi-Fi® Access Point that provides network connectivity to multiple cabin users with a programmable digital I/O. The unit has eight Ethernet LAN 10/100 ports, and can support 54 wireless clients using the 802.11-b/g protocols.

4.6.5 Test vehicle computer and data provisions

The existing flight-test provisions on the aircraft comprise a dedicated workstation, an auxiliary computer (“R2D2”), and sophisticated data interfaces to the aircraft’s systems. The flight test workstation contains a powerful dual-core computer interfaced with 32 ARINC 429 busses, 32 discretes, and a Wi-Fi broadcast system. The workstation also incorporates a 15-inch XGA display and a six-channel digital video recorder, with internal and external camera feeds. Workstation SGA video can also be routed to the 8”x10” Multi-Function Display (MFD) on the copilot’s instrument panel which can function as a Class 3 EFB. The “R2D2” auxiliary computer is also interfaced to several of the aircraft’s ARINC busses through the AID, has Wi-Fi capability, and can drive the copilot’s MFD remote display. Both the workstation and R2D2 computers are capable of hosting TAP, although these are not the principal TAP computers. No changes were required to these systems for the TAP flight trials.



Figure 7. Test-bed cockpit. The EFB is mounted on the right-side windshield.

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4.7 System Test and Evaluation

The TAP testing is detailed in numerous program documents, including the Flight Trial Research Plan and the Flight Test Plan. The following sections highlight important details from these plans.

4.7.1 Incremental Test Approach

An incremental risk-mitigation approach was applied to the preparation for the flight trials. Testing began with the development of functional human factors mockups of the TAP software, followed by a number of incremental builds of the operational software. Three sets of simulations were conducted to validate different performance aspects of the TAP software:

1. Extensive testing was performed at the NASA ATOL to verify the basic TAP algorithms and validate the proposed test scenarios.
2. End-to-end simulations were conducted at the Operator Performance Laboratory (OPL) of the University of Iowa to refine the TAP software, interfaces, operating procedures, Human-Machine Interface (HMI), and test procedures (including briefings, debriefings, questionnaires, etc.).
3. Further simulations were conducted using AdvAero's systems and human factors simulator, which has an avionics architecture designed to replicate the Avanti aircraft.

The objective of these tests was to further debug the TAP software and integration with the aircraft data systems. An additional goal was to practice and refine the specific test scenarios to be used during the flight trials.

4.7.2 Flight Test Program

The flight test program began upon the successful conclusion of the simulator evaluations and incorporated lessons learned from the simulations, where practical. Initial testing comprised 30 hours of opportunity “shakedown” testing with the TAP system installed and functioning while the aircraft was engaged in other duties. The purpose of the shakedown tests was to further debug the TAP integration with the aircraft systems. The shakedown phase was followed by a 36-hour formal test program, including ten formal assessment missions and two demonstration flights.

4.7.3 Individual Flight Profiles

The formal flight-testing was designed to exercise TAP functionality in four increasingly challenging steps:

1. Verification of the operational data flows to TAP, and verification that TAP was able to successfully process the information in real-time.
2. Verification of TAP interface functionality, per the system requirements.
3. Observation of test subject interactions with TAP in an operational environment.
4. Use of TAP to generate an aircrew request to ATC, with optional execution of the request.

A nominal TAP flight comprised a 2.5-hour profile, of which approximately 30 minutes were allocated to the departure and arrival segments below 10,000 feet where TAP was in Standby mode. The remaining 120 minutes of flight above 10,000 ft. were dedicated to the TAP In-Flight Assessment. A typical sequence of test events is shown in Table 4.

Table 4.
TAP Mission Test Activity Sequence

Time	Operation
TO – 10 minutes	<ul style="list-style-type: none"> • Power-up aircraft • Power-up flight test engineers computers and EFB
TO - 9 minutes	<ul style="list-style-type: none"> • Validate data is flowing to each TAP installation
TO - 2 minutes	<ul style="list-style-type: none"> • Power-down and stow all non-essential hardware
TO	<ul style="list-style-type: none"> • Take off
TO + 15 minutes	<ul style="list-style-type: none"> • Alt > FL100 • Power up flight test engineers computers and EFB • Validate data is flowing to each TAP installation • Flight assessment scenarios
Landing - 20 minutes	<ul style="list-style-type: none"> • Prepare for landing < FL100 • Power down and stow all non-essential hardware
Landing	<ul style="list-style-type: none"> • Landing
Landing + 1 minute	<ul style="list-style-type: none"> • Power-up flight test engineer computers, if necessary • Backup all collected data • Power-down flight test engineer computers
Landing + 10 minutes	<ul style="list-style-type: none"> • Power-down aircraft, Exit

Note. Adapted from NASA Flight Test Operations and Safety Report (FTOSR) (Project Reference N).

All of the flight plans comprised outbound and inbound phases, terminating at the airport of origin as shown in *Figure 8*. Each phase comprised a number of legs upon which the TAP optimizer acted. Special Use Airspace (SUA), which must be avoided, was incorporated in some of these routings to challenge the TAP trajectory optimizer.

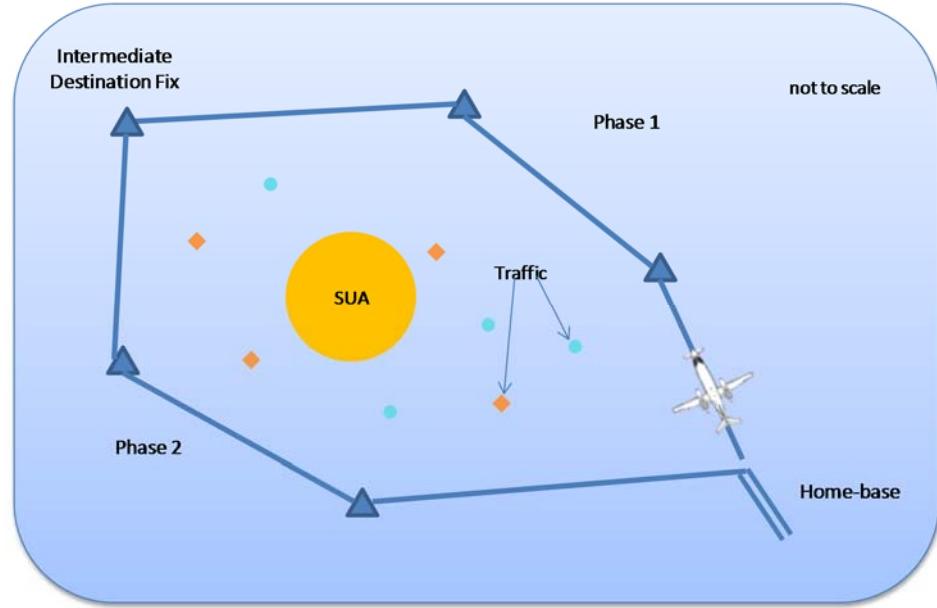


Figure 8. Representative TAP test - plan view. © 2014 Advanced Aerospace Solutions, LLC. Reprinted with permission.

The vertical test profiles were all conducted at a constant predefined cruising altitude above 10,000 feet, the floor for TAP operations, as shown in *Figure 9*. Vertical deviations resulting from optimizer recommendations were allowed.

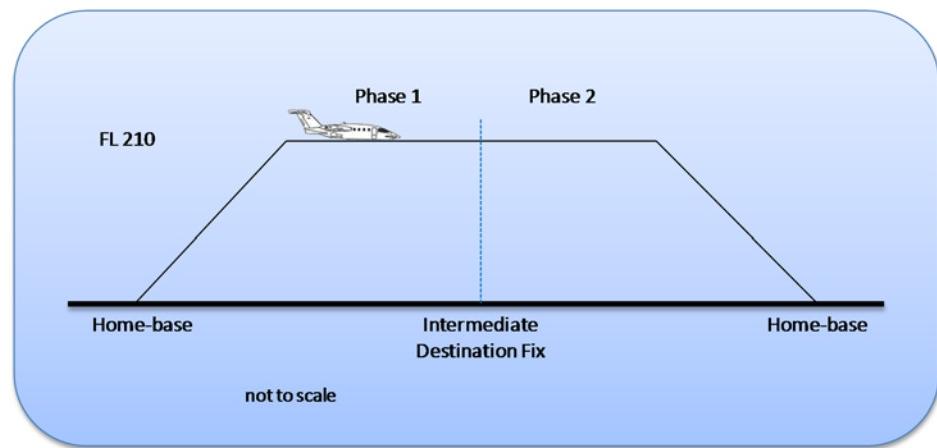


Figure 9. Representative TAP test - profile view. © 2014 Advanced Aerospace Solutions, LLC. Reprinted with permission.

4.7.4 Flight Test Envelope

All TAP operations were conducted near the center of the aircraft's Normal Category flight envelope. The TAP system remained in Standby mode below 10,000 ft. MSL, the floor altitude for the TAP evaluations. Aircraft payload/range limitations effectively limited the maximum altitude to FL380 (the aircraft's certified ceiling is FL410). TAP operations were conducted near the aircraft's maneuvering speed (approximately 200 KIAS / 260 KTAS @ FL150), which afforded the maximum margin between the stall and Mmo/Vmo conditions. TAP evaluations were conducted with the autopilot engaged, which ensured that all maneuvers remained within the aircraft's certified flight envelope. These parameters are summarized in Table 5.

Table 5.

TAP Evaluation Flight Test Envelope

Parameter	Planned Value	Notes
Altitude	FL150 – FL200	FL100/MEA Minimum FL300 Maximum
Airspeed	200 – 220 KIAS	Approximately Va
Lateral TAP Maneuver	Autopilot turn-to-heading	
Vertical TAP Maneuver	Autopilot climb/descent	
Load Factor	Max 1.15 (30° Bank)	Autopilot limited
Autopilot Mode	Autopilot and Yaw Damper engaged	
Weight and Balance	Within normal envelope	
Aircraft Certification	Part 23 Normal Category C of A	
Weather	VMC/IMC	

Note. Adapted from NNL12AA06C (Project Reference N).

4.8 Construction/Production Requirements

The principal TAP aircraft modifications used COTS products installed by authorized aircraft modification centers in accordance with the applicable regulations and facility certifications.

4.9 System Utilization and Sustaining Support

All TAP COTS hardware is maintained and supported in accordance with manufacturer's procedures using approved service resources. The TAP software was maintained by the software specialists involved in the program. TAP is designed to be uninstalled between flight trials, and will therefore not require any ongoing support.

4.10 System Retirement and Material Recycling/Disposal

All modifications incorporated for the TAP program were FAA certified and permanently installed in the aircraft. The systems will remain installed to facilitate planned future testing until obsolescence or unserviceability dictate. In this event, the equipment will be disposed of in accordance with appropriate procedures for COTS electronics.

5 TECHNICAL PROGRAM PLANNING, IMPLEMENTATION, AND CONTROL

5.1 Program Requirements/Statement of Work (SOW)

The TAP SOW (project reference K) is confidential, but key program objectives pertaining to this SEMP include:

1. Selection, with technical justification, of a Class 2 EFB hardware system to host the TAP software for developmental testing.
2. Integration of TAP with the selected Class 2 EFB hardware system.
3. Support for broadband Internet connectivity for the provision of external TAP data.
4. Minimal changes to existing avionics architectures or displays for near-term forward-fit applications.
5. Accomplish FAA certification and NASA operational approvals for the conduct of the TAP flight trials.
6. Conduct an in-flight assessment of the TAP Application with the objective of identifying operational factors unique to the in-flight environment that may affect TASAR application functionality, data requirements, Human-Machine Interface (HMI), and operational procedures, with the objective of refining the TAP application and concept.

5.2 Organization

The TAP program originated from NASA Research Announcement NNH10ZZEA001N, Research Opportunities in Aeronautics – 2010, Amendment 7, Subtask 5, Traffic Aware Strategic Aircrew Requests (TASAR) Analysis and Development. The contract was awarded to Engility Corporation as the Prime Contractor, with AdvAero as the subcontractor. A parallel and independent contract was awarded to the University of Iowa Operator Performance Laboratory (OPL) for the conduct of some of the full flight-deck TAP simulations.

5.2.1 Producer/Contractor Organization

The project customer was NASA Langley and the producers were Engility (Prime) and AdvAero (sub contractor). AdvAero was the flight test lead, reporting directly to NASA for the conduct of the flight tests. The AdvAero research aircraft remained under the operational control of Skyservice of Montreal.

5.2.2 System Engineering Organization

AdvAero adopted an Integrated Product Team for the system engineering functions, as shown *Figure 10* below. Some of the positions were filled by the same individuals as noted in section 6.1, except for those designated as independent in the figure.

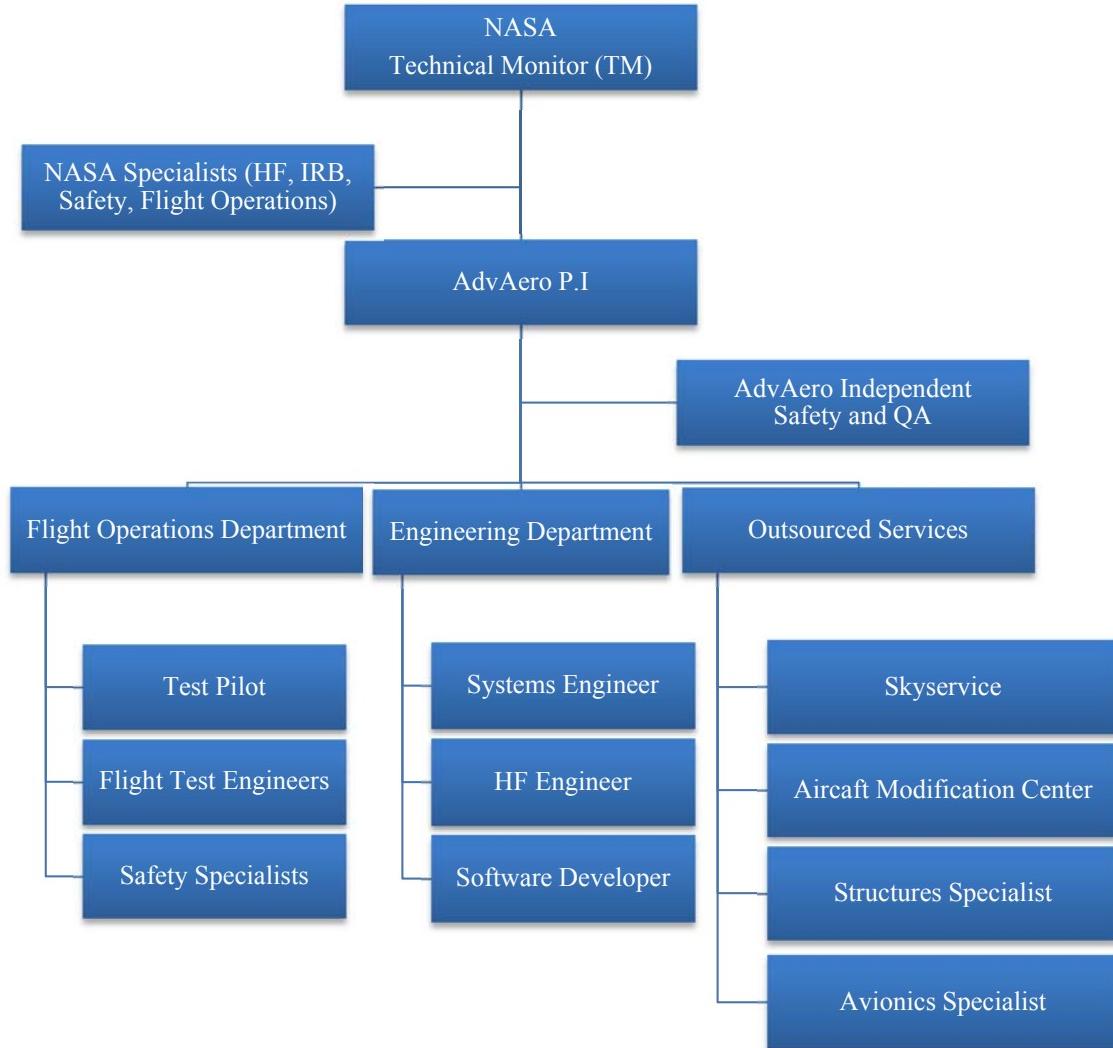


Figure 10. AdvAero TAP Integrated Product Team. © 2014 Advanced Aerospace Solutions, LLC. Reprinted with permission.

5.2.3 Program Tasks

The system engineering program tasks approximated Blanchard's outline (2008, fig. 6.6), as shown in Table 6 below.

Table 6.

TAP Principal Flight Test System Engineering Tasks

Output	Primary Responsibility
Develop Concept of Operations	Prime contractor
Develop operational Use Cases	Prime contractor
Develop flight-trial aircraft modifications plan	AdvAero
Develop HMI Mockup	AdvAero
Define flight-trial approval requirements	AdvAero
Prepare flight-trial PER presentation package	AdvAero
Prepare benefits assessment report	Prime contractor
Develop flight-trial research plan	AdvAero
Perform flight-trial hazard analysis	AdvAero
Select Class 2 EFB system	AdvAero
Develop TAP prototype build	Prime contractor
Develop Pilot Procedures	AdvAero
Prepare Flight-trial IRB approval package	AdvAero
Prepare Flight Test Operations and Safety Report (FTOSR)	AdvAero
Present flight-trial Final Experimental Review	AdvAero
Prepare flight-trial approval artifacts package	AdvAero
Prepare flight-trial Readiness Review (FTRR) package	AdvAero
Prepare flight-trial reports	AdvAero
TAP final build	Prime contractor
Develop HMI-procedures design guidelines	All
Prepare final report	All

Note. Adapted from project SOW (Reference K).

5.2.4 Supplier Requirements

Requirements for equipment suppliers and sub-contractors to AdvAero are fully defined by the applicable Federal Aviation Regulations. All applicable quality requirements from the project SOW were flowed down to these suppliers, ensuring that overall program quality goals were maintained.

5.3 Key Organizational Interfaces

The key organizational interfaces differed between contractual and system engineering viewpoints. Contractually, the AdvAero Chief Operating Officer reported via the Prime Contractor's Principal Investigator (P.I.) to the NASA Technical Monitor. In practice, a number of peer-to-peer reporting paths were followed for efficiency purposes, with all pertinent information being sent in parallel via the contractually mandated path. These paths are shown in the table below:

Table 7.

TAP Reporting Interfaces

Function	Interface
Program administration	AdvAero COO to Prime P.I.
Flight operations and safety	AdvAero P.I. to NASA T.M.
Safety and QA	AdvAero P.I. to NASA T.M.
Software engineering	Peer-to-peer, cc. P.I.

Note. Adapted from project SOW (Reference K).

5.4 Work Breakdown Structure (WBS)

The detailed WBS is contained in the *Flight-Demonstration Aircraft Modification Plan* (Reference A), which is incorporated into this SEMP by reference. The top-level work packages were as follows:

- 5.4.1 Class 2 EFB selection and installation and certification
- 5.4.2 AID selection, installation, and certification
- 5.4.3 Autopilot-state annunciation interface
- 5.4.4 EFB Landing gear and flap position sensing
- 5.4.5 ADS-B TCAS upgrade
- 5.4.6 TCAS / transponder control head upgrade
- 5.4.7 ADS-B transponder upgrade
- 5.4.8 Satellite broadband system selection, installation, and certification
- 5.4.9 Broadband antenna installation
- 5.4.10 Miscellaneous TAP Provisions
- 5.4.11 Workstation data and video interfaces
- 5.4.12 Workstation power switch relocation

5.5 Project Schedule and Milestone Charts

The project schedule is shown in *Figure 11* on the following page.

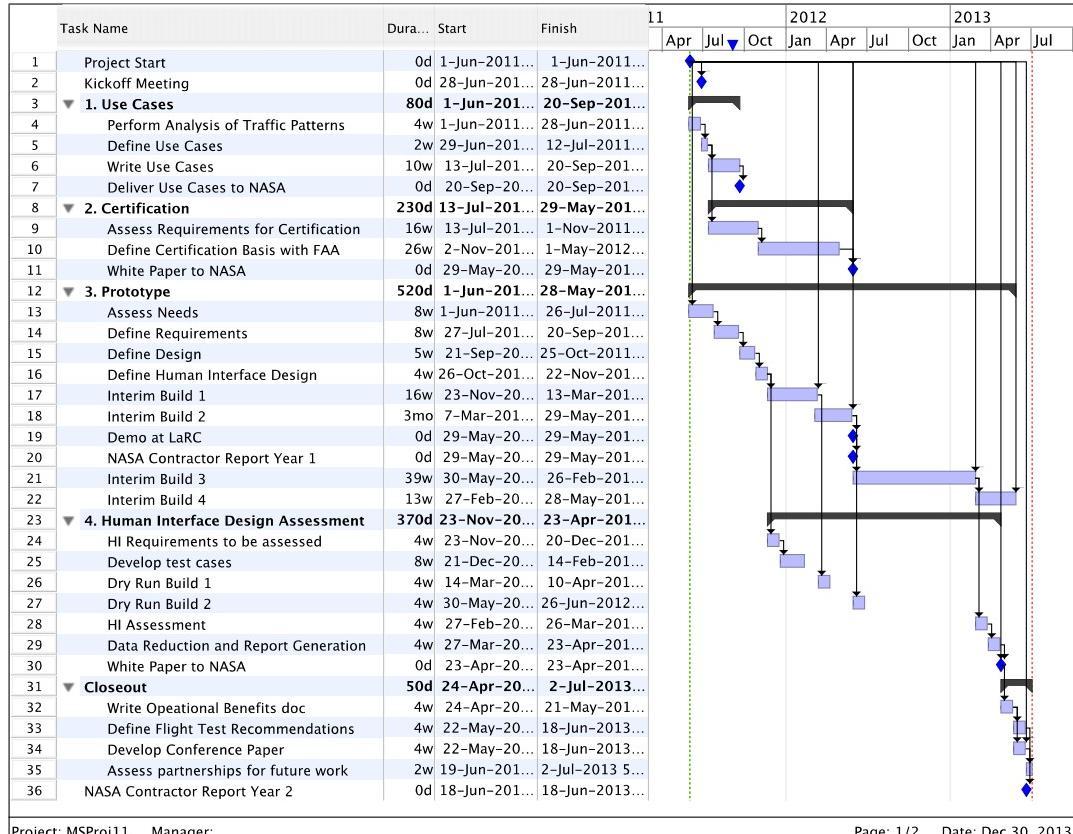


Figure 11. Program schedule © 2014 Advanced Aerospace Solutions, LLC.

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The milestones leading to the flight demonstrations included:

1. ASRB Design and Operational Safety Reviews
2. Institutional Review Board (IRB) Review
3. ATOL TAP Build 2 integration testing
4. AdvAero Simulator TAP HMI evaluations
5. University of Iowa Operator Performance Laboratory (OPL) Use Case evaluations
6. Final Experimental Review Briefing
7. Flight Trial artifact approval
8. Flight Trial Readiness Review data package distribution
9. ATOL TAP Build 3 integration testing
10. Flight Trial Readiness Review (FTRR)
11. Flight Release Issuance
12. Flight Demonstrations

5.6 Technical Performance Measurement “Tracking”

The NASA Technical Monitor was responsible for tracking performance measures, primarily using qualitative methods. This was primarily achieved via the regular status reviews and acceptance of the formal deliverables discussed in sections 5.8 and 5.9, respectively.

5.7 Program Cost

NASA awarded the TAP flight test program under a firm-fixed-price contract. The cost details are confidential. Internally, AdvAero maintains Key Performance Indicators, earned value metrics, and cost data using the Ceridian Dayforce™ system.

5.8 Technical Communications

The primary means of technical communications was via scheduled weekly conference calls of approximately two hours duration between the NASA Technical Monitor, NASA support experts, and the prime contractor’s and sub-contractor’s teams. These calls will be increased in frequency – in some cases daily, or even hourly, during the flight trial execution. When necessary, direct peer-to-peer communications between engineers were authorized, and the Principal Investigators (PI) were always kept informed of the outcome of such discussions. The weekly meetings were supplemented by monthly status reports, semi-annual meetings, and numerous formal documentation deliverables as discussed below.

5.9 Program Monitoring and Control

The NASA Technical Monitor (TM) was responsible for the monitoring and control of the program. The two Principal Investigators from Engility and AdvAero were, in turn, responsible for achieving the software and flight test objectives, respectively. Issues were addressed at the lowest level of the reporting hierarchy and escalated as necessary up to the TM, with an attitude of full and open communications and disclosure. The PIs provided formal monthly status reports that updated and summarized the accomplishments, action items, program risks and mitigations since the last report. The TAP test team also attended semi-annual meetings at NASA Langley, and additional meetings were convened on an opportunity basis during intervening essential on-site reviews. These included the preliminary and final Flight Test Operations and Safety Report (FTOSR) presentations to the NASA Airworthiness and Safety Review Board (ASRB).

5.9.1 Operator Certification & Training Standards

AdvAero’s test aircraft is professionally maintained, operated, and managed by Skyservice of Montreal, QC, Canada (<http://www.skyservice.com/managedservices.php>). Skyservice was founded in 1986, and is one of Canada’s premier full service business aviation

organizations. The test aircraft operations were governed by Skyservice processes pertaining to Part VII, Subpart 702, of the Canadian Aviation Regulations (CARs) (Aerial Work – Flight Test Operations). The aircraft and crew were also fully certified by Skyservice to operate under CAR Subpart 703, Air Taxi operations. Skyservice has a comprehensive Safety Management System (SMS) approved by Transport Canada to Air Carrier standards.

5.9.2 Operator Audit

An on-site NASA safety audit of the test aircraft, its installed systems, and the applicable documentation was successfully concluded on March 13, 2013 at the Newport News / Williamsburg International Airport (KPHF), in parallel with the FTOSR.

5.9.3 Flight Test Governance

AdvAero's flight operations are governed by Skyservice's Transport Canada-approved Company Operations Manual (COM) and Safety Management System (SMS), which include provisions for 24/7 flight following and alerting. AdvAero's flight-test operations are further governed by its Transport Canada-approved Flight Test Operations Manual (Project Reference B). This document is more conservative than the stringent commercial air carrier specifications that normally govern the operation of the test aircraft. The FTOM addresses the top-level policy and requirements for the following operational aspects of all AdvAero flight- test programs:

1. Categories of flight test;
2. Flight test operations control system;
3. Safety and risk management system;
4. Aircraft modifications;
5. Flight authorities;
6. Test planning and conduct;
7. Aircrew qualifications, training and currency;
8. Duty time limitations;
9. Record-keeping procedures; and
10. Delegated function.

All flight operations were conducted in compliance with the more conservative of the following applicable documents and regulations:

- Federal Aviation Regulations (FARs);
- Transport Canada Civil Aviation Regulations (CARs);
- Skyservice Company Operations Manual;

- AdvAero Flight Test Operations Manual (Project Reference B);
- NASA Procedural Requirements: Aircraft Operations Management Manual NPR 7900.3C □(Project Reference Y). □

The AdvAero FTOM was submitted to NASA on June 11, 2012 for validation against the requirements of□NPR7900.3C and approved by LARC-D1 on July17, 2012.

5.9.4 Aircraft Maintenance

SkyService maintains the test aircraft to Transport Canada Air Carrier (CAR 703) standards. The company employs factory-trained personnel (Piaggio Aircraft Industries and Pratt & Whitney Canada), and all maintenance releases are performed by Transport Canada certified personnel. The aircraft's PT6A-66 engines are maintained to the highest available Pratt & Whitney standard ("ESP Gold"), and the majority of the avionics are either new, or registered under the manufacturer's ongoing warranty plans. The aircraft is always hangared at its home base and when it is deployed, subject to availability.

SkyService maintains on site a complete electronic and/or paper subscription of all required maintenance and technical documentation for the aircraft, its engines, systems, and avionics. All maintenance is tracked electronically using Avtrak® software as shown in *Figure 12*.

Figure 12. Sample Avtrak® maintenance tracking software printout.

6 ENGINEERING SPECIALTY INTEGRATION

6.1 Functional Engineering

The following engineering disciplines were employed for the TAP development and testing. Several of the roles were combined for this program:

1. Test Pilot;
 2. Flight Test Engineer (FTE);
 3. System Engineer;
 4. Safety Specialist;
 5. Avionics specialist;
 6. Structural Engineer;
 7. HF engineer; and
 8. Software developer.

6.1.1 Test pilot

The test pilot, who was also the P.I. for the flight test program, was responsible for the safe and efficient planning and conduct of the flight tests. He was also delegated to perform the overall systems engineering and certification activities for the test installation, including the

Flight Analyst, Human Factors, and TSO approvals. The test pilot acted as the safety monitor and final authority for decision-making during the flight tests.

6.1.2 Flight test engineer

FTEs were responsible for the safe and effective operation of the installed test and safety equipment in the aircraft. The in-flight Test Director was appointed from the flight test engineer specialty, as were the Data Engineers. All FTEs also performed system-engineering functions for their specialized subsystems.

6.1.3 Safety specialist

The Test Pilot / P.I. and Test Director were the two designated safety specialists for this program. The safety specialist was responsible for leading the safety planning processes, and was directly accountable to the NASA safety organization structure. The Test Director safety specialist also led the Institutional Review Board (IRB) activities related to the experimental design and protection of the human subjects.

6.1.4 Avionics specialist and structural engineer

Both the avionics specialist and structural engineer disciplines were outsourced as part of the avionics installation activity. The avionics specialists and structural engineering disciplines were required for the FAA certification of the TAP hardware. The avionics specialist was responsible for the safety analysis of the avionics architecture for the safe certified systems. The structural engineer was required to perform the analysis of the ADS-B antenna installation, which required specific FAA approval because it pierced the 9.0-PSI cabin pressure vessel.

6.1.5 HF engineer

The HF engineer was responsible for the ergonomic design, HF evaluation, and HF compliance of the installed TAP equipment. The Flight Test P.I. performed this function. This discipline differs from the prime contractors HF engineer, who was responsible for the human factors of the TAP display.

6.2 Software Engineering

This SEMP does not address the TAP software engineering, except to the degree that it impacted the overall system design. AdvAero software developers performed all analysis, design, and coding for the aircraft-side integration of TAP with the other aircraft systems. A classic “design to the interfaces” approach was adopted for this task. The data and mechanical ICDs were therefore of paramount importance, and required continual updating as the highly

iterative development program evolved. AdvAero employed Agile™ techniques to ensure that the interim system engineering builds were functional and available for integration testing by its partners. Similarly, the prime contractor delivered a number of interim TAP software builds for use in the system integration testing activity. A classic waterfall software development model would not have worked in this environment, because of the time constraints and inter-dependencies of this highly iterative development program.

6.3 Reliability Engineering

No dedicated reliability engineering was performed because of the extensive use of COTS components and the FAA-certified installation. The test system inherited the reliability engineering from these processes and certifications. This SEMP does not address the TAP software development program, whose reliability engineering considerations remain proprietary to Engility Corporation.

6.4 Maintainability Engineering

The hardware installed for this program was COTS sourced and the sub-system installations were FAA certified for aviation applications. Careful consideration was given to the maintainability aspects of the EFB equipment, particularly regarding in-flight access for troubleshooting purposes. The TAP software incorporated extensive built-in test, logging, and debugging provisions, and a software engineer was dedicated to monitoring the application's health status during the flight trials. No maintainability problems were encountered related to the system installation.

6.5 Human Factors (HF) Engineering

The HF engineering for the COTS test installations was in accordance with the Intended Function provisions of 14 CFR 23.1301, as determined by the program P.I. and test pilot. No specific additional HF processes were employed for the aircraft modifications.

Although this SEMP does not address the HF engineering for the TAP software, the process did have an influence on the system and test design. The program was governed by NASA's Institutional Review Board (IRB) processes, including all required experimental reviews. All test team personnel with possible contact with the test subjects were required to take on-line IRB training from the Collaborative Institutional Training Initiative (CITI).

The test design entailed the generation of a number of Use Cases (Reference I) designed to probe TAP's functionality. Robust Pilot Procedures were created from the Use Cases as the backbones for the airborne TAP evaluations, and the detailed flight plans were derived from these Pilot Procedures. An incremental methodology governed the build up of the test cases, commencing with rapid-prototyping usability studies, through two levels of simulation, and

culminating in the flight evaluations. Ten test-subjects were scheduled to fly a single 2.5-hour mission as part of a between-subjects design.

TAP was evaluated through a highly structured test program using the Bedford Workload rating scale (*Figure 13*), hand-recorded data, in-flight surveys, digital audio/video recordings, and extensive recording from the aircraft's ARINC 429 data-busses and from the computers hosting TAP. The survey instruments were evaluated during the OPL pilot simulation studies and during a dry run which preceded the first formal flight evaluations. Prior to their flight, each subject received a two-hour formal preflight experimental briefing and TAP training session. During the flights, the Test Director administered comprehensive subjective questionnaires and Bedford assessments to the test subject at several break points during each mission. An additional one-hour electronic survey (using Lime software) was administered to each subject during the mission debriefing within an hour of flight completion. This formed the basis of a two-hour open debriefing, attended by most of the test team members as well as NASA human factors specialists. The paper and electronic surveys were supplemented by full-time digital cockpit audio/video recordings and comprehensive digital recordings from each computer hosting TAP. The existing aircraft-side data systems also allowed a keystroke-by-keystroke recreation of each FMS button-push and readout, with a complete cockpit visualization capability and Google Earth™ flight path recreation. The ARINC 429 data logging also allowed each profile to be replayed through AdvAero's research simulator. All of these data will be used to evaluate TAP's performance and to improve its functionality and interface.

An intense 36-hour flight test program was successfully completed in two weeks, marred only by a single aircraft unserviceability unrelated to the TAP installation. Based on the preliminary data reduction, many significant and useful findings have already been made in relation to the original program objectives.

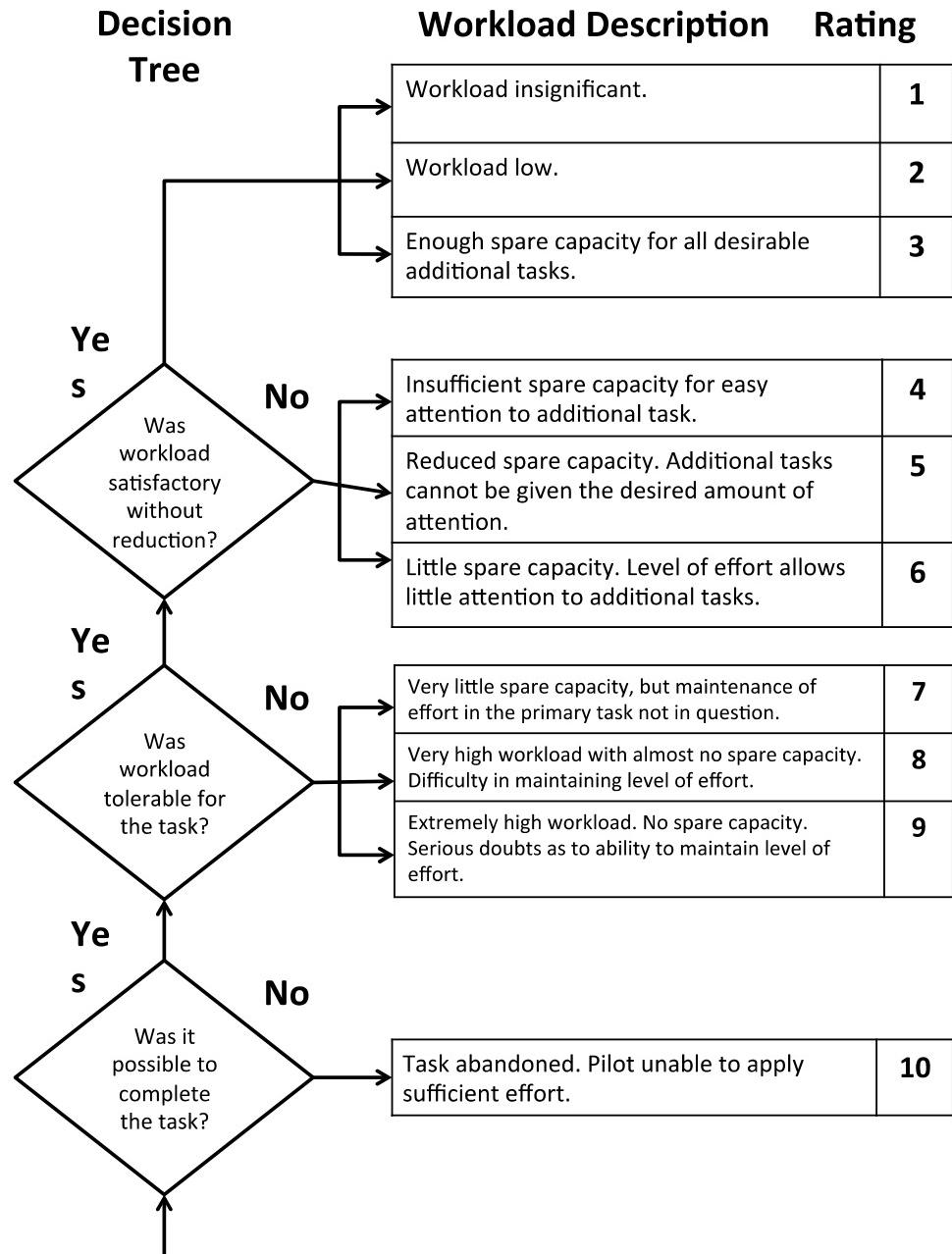


Figure 13. Sample Bedford workload rating scale.

Adapted from Roscoe and Ellis, 1990.

6.6 Safety Engineering

The test-vehicle is FAA certified with a Normal Category C of A under 14 CFR Part 23. The aircraft incorporates a fully firewalled flight-test architecture which functionally and physically partitions the copilot's test station from the triple redundant safety pilot's (captain's) station as shown in *Figure 14*. This partitioning required the aircraft to be certified for single-pilot operation, as previously discussed.

All equipment installed for the TAP flight-trials was FAA certified and therefore compliant with the safety engineering requirements for its respective certification basis. In general, major aircraft modifications were certified using the Supplemental Type Certificate (STC) process. Individual systems were certified via Technical Standard Order (TSO) approval, where applicable. These certifications invoked RTCA DO-160 (Reference CC) for environmental certification, DO-178B (Reference DD) for software, and DO-254 (Reference FF) for computer hardware. The System Safety processes defined in SAE ARP 4754 (Reference HH) and AC 23-1309-1E (Reference DD) were followed for the overall system integration and hazard analyses.

The Principal Investigator, a Canadian government Design Approval Representative test pilot, evaluated the TAP installation during several dedicated test flights and 30 hours of shakedown testing, for safety and human factors acceptability, prior to the issuance of the certification and operational approvals of the system. No substantive issues or shortcomings were noted, and the TAP flight evaluations were completed without incident, with the exception of a single, unrelated, aircraft system unserviceability.



Figure 14. Test-vehicle cockpit partitioning. © 2012 Marinvent Corporation.

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6.7 Security Engineering

The TAP software has no ability to affect other aircraft systems because of its advisory nature. Accordingly, there were no specific Security Engineering considerations for this program.

6.8 Manufacturing and Production Engineering

With the exception of the TAP software and small miscellaneous wiring harness materials, all equipment for this program was COTS. Accordingly, there were no manufacturing or production engineering considerations, except for lead-time allowances and aircraft downtime scheduling.

6.9 Logistics and Supportability Engineering

With the exception of the TAP software, all systems related to the test program were FAA certified COTS items. The logistics and support were therefore based on the normal supply chain for the test vehicle and its systems.

6.10 Disposability Engineering

All COTS items will be disposed at the end of their useful lives using industry best practices.

6.11 Quality Engineering

With the exception of the TAP software, all COTS equipment will be certified in accordance with the quality standards applicable to the equipment's respective certification basis. The TAP software was developed using best industry practices for software rapid prototyping activities.

6.12 Environmental Engineering

The TAP flight trials involved the normal operation of a 14 CFR Part 23 certified General Aviation aircraft. There were therefore no specific environmental engineering considerations, although the Avanti test-vehicle is the world's most fuel-efficient multi-engine turbine business aircraft, which conferred obvious environmental benefits to the program.

6.13 Value/Cost Engineering

As with any complex fixed-price research project, very careful control was maintained over program costs. The major cost influence was "scope creep" from two sources: (1) early successes encouraged the leadership team to adopt more ambitious goals as the program progressed; and (2) the parallel rapid-prototyping activity between the four main stakeholders proved resource intensive. Countering these factors, the chosen test-vehicle was already very well equipped to accommodate the proposed testing, which minimized overheads and non-recurring expenses. Significant efforts were made to ensure that the system architecture was scalable and resistant to obsolescence. This was achieved by the extensive use of expandable COTS components that featured software updates to accommodate upcoming capabilities.

6.14 Other Engineering Disciplines

N/A

7 CONFIGURATION MANAGEMENT

All artifacts produced by this program were subject to full versioning, access control, and configuration management, as dictated by NASA. AdvAero uses MKS Source Integrity™, Atlassian™ collaboration tools, and CertPro, a flight test suite developed by AdvAero for flight test planning and control.

8 DATA MANAGEMENT (DM)

Data collection included video, digital, and hand-recorded media were all managed using the collaborative tools described above. Of particular importance, all test subject data were de-identified in accordance with NASA IRB procedures defined in the Flight Trial Research Plan and Flight Trial Test Plan.

9 PROGRAM TECHNOLOGY REQUIREMENTS

With the exception of the NASA ATOL facility (Sections 0 and 4.7.1), the prime and subcontractor teams provided all the required technologies to perform the software programming, system engineering, and flight-test tasks associated with the program.

10 SPECIAL INTERNATIONAL REQUIREMENTS

The Avanti test-platform is a Canadian-owned and registered aircraft. Accordingly, revenue flight-test operations in the U.S.A. required specific FAA authorization. This was achieved via OpSpec #056 “NAFTA approval for flight-test operations by C-GJMM in U.S. Airspace” which remains in force until Mar 1, 2014.

11 RISK MANAGEMENT

The TAP flight-trial risk management process was governed by the most conservative criteria from the following documents:

1. The NASA Airworthiness and Safety Review Board (ASRB) Process LMS CP-5580 (*Figure 15* and *Figure 16*);
2. The AdvAero Flight Test Operations Manual (Project Reference B);
3. Skyservice SMS Manual (Project Reference P); and
4. The applicable Federal Aviation Regulations (FAR).

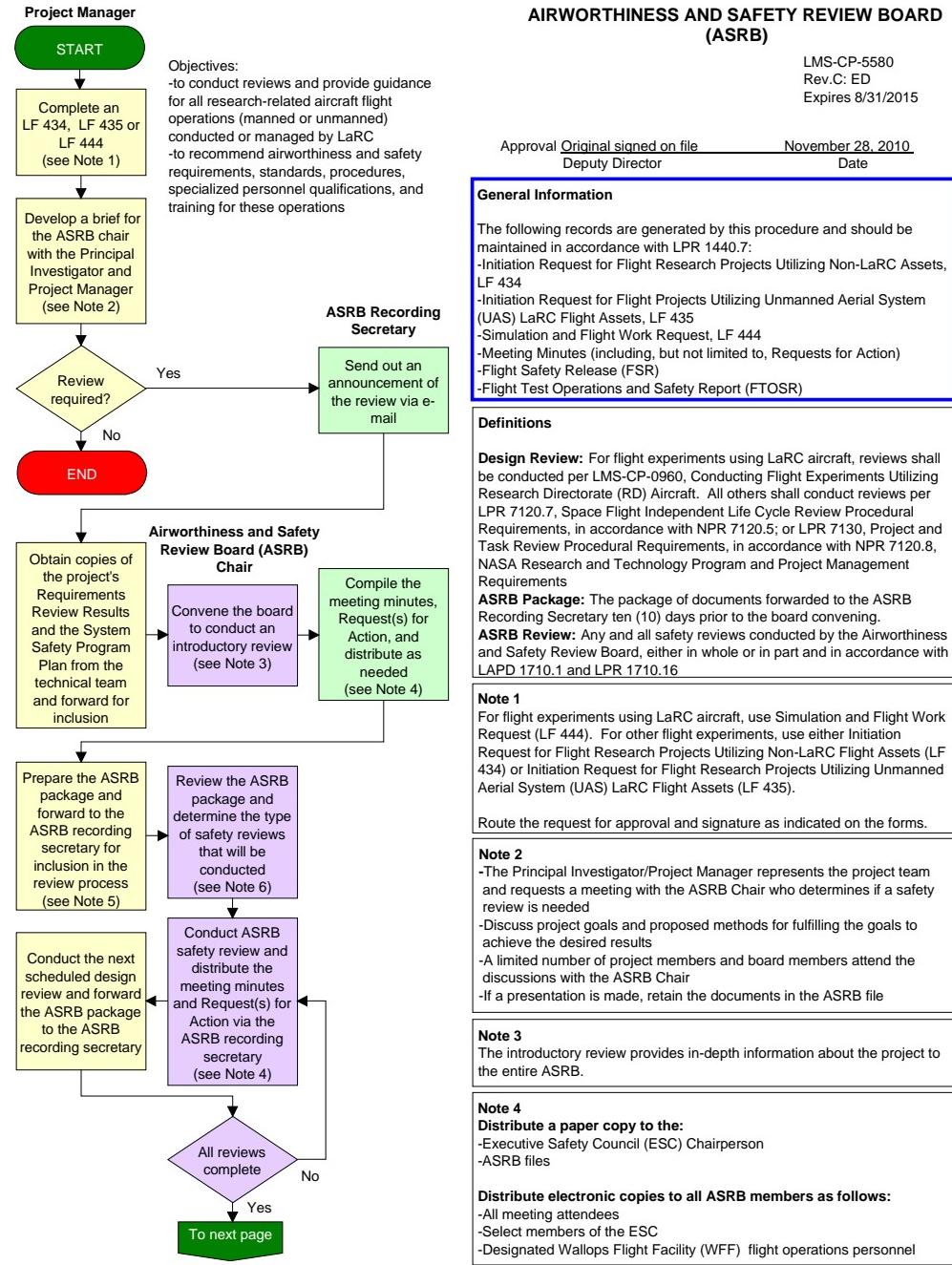
The following points contained in these documents were salient to the Hazard Analysis:

1. The test aircraft will operate under an unrestricted Normal category Certificate of Airworthiness, with approvals for day, night, VMC, and IMC operations, including approval for flight in known icing conditions.
2. All TASAR modifications were certified via a Supplemental Type Certificate (STC) process, and none of the equipment was experimental.
3. The aircraft is equipped with state-of the art avionics, including Kalman filtered Inertial Navigation System (INS)/GPS navigation with approach capability, Enhanced Ground Proximity Warning System (EGPWS), TCAS, satellite data-link, Doppler radar, and lightning detection. This equipment exceeds the requirements of section §3.1.3.6 of the Aircraft Operations Management Manual (NPR7900-3C - reference Y) pertaining to FAA-approved TCAS and EGPWS systems.
4. The aircraft was operated and maintained by Skyservice, a leading aircraft management company, and maintained using Avtrak® computerized maintenance tracking. The

aircraft's engines are maintained to the highest available Pratt & Whitney standard ("ESP Gold"), and the avionics are under the manufacturers' warranties.

5. The Pilot-In-Command was an experienced graduate of a recognized one-year Test Pilot school, and the aircraft was operated to Public Transport standards by a professional crew licensed for such operations, in compliance with the provisions of LMS-CP-0904, "*Authorizing Flight Aboard Non-LaRC Aircraft*" (Reference R).
6. AdvAero's routine operations are governed by Skyservice's Company Operations Manual (COM) and Safety Management System (SMS), which includes 24/7 flight following. AdvAero's flight-test operations are further governed by its Transport Canada-approved Flight Test Operations Manual (Reference B). The FTOM is generally more conservative than the stringent commercial air carrier specifications that normally govern the operation of the test aircraft.

The AdvAero FTOM was accepted by LaRC Flight Operations as compliant with NASA's NPR 7900.3C *Aircraft Operations Management Manual* (reference Y). The TASAR Flight Test Operations and Safety Report (Reference N) and Hazard Analysis (Reference L) received approval by the NASA Airworthiness and Safety Review Board (ASRB) on Mar 14, 2013 and a Flight Safety Release (FSR) was issued on September 11, 2013 to conduct the flight demonstrations per LMS-CP-5580. The FSR remained in force until December 20, 2013, approximately one month following the completion of the TAP flight trials.



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Verify correct revision before use by checking the LMS Web Site

Figure 15. NASA Airworthiness and Safety Review Board (ASRB) Process.

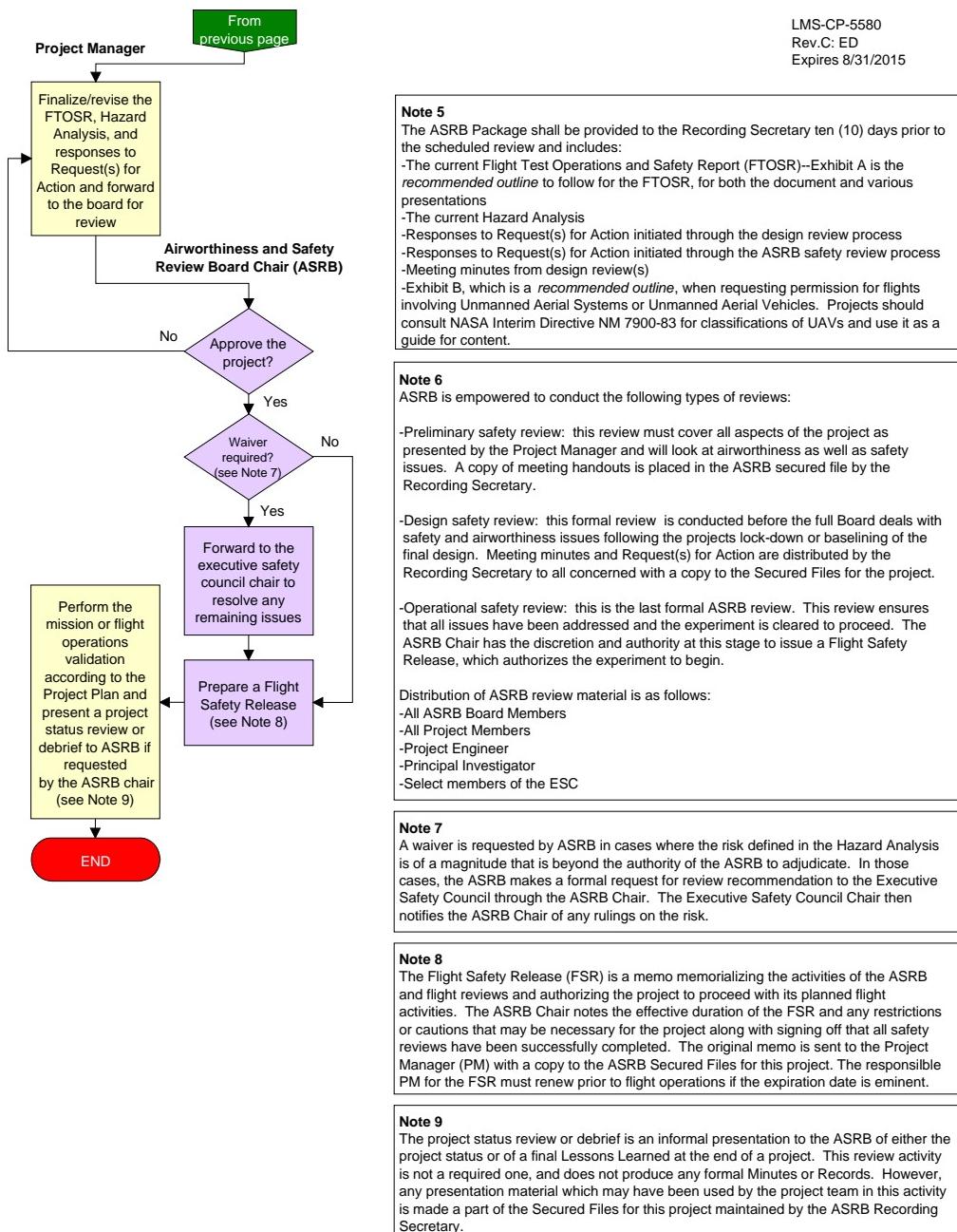


Figure 16. NASA ASRB process (cont.)

A summary of the Hazards, Mitigations, Residual Risk severity, and Residual Risk probability are shown below. The overall assessment was an Extremely Improbable chance of a catastrophic failure condition, which represents a LOW overall risk.



NASA TASAR / TAP Safety Briefing		
TEST OBJECTIVE(S)	MISSION DATE/SEQUENCE:	AIRCRAFT: C-GJMM
1. Verification of the operational data flows to TAP, and that TAP is able to successfully process the information in real-time. 2. Verification of TAP interface functionality, per the system requirements. 3. Observation of test subject interactions with TAP in an operational environment. 4. Use of TAP to generate an aircrew request to ATC, with optional execution of the request.		
HAZARDS AND UNDESIRED EVENTS Per approved Forms 273 from FTOSR v1.3 dated August 16, 2013		
001	Damage to aircraft structure due to crew distraction or workload could lead to an aircraft limitation being exceeded (e.g. Vmo/Mmo, limit load factor, etc.)	
002	Personal injury due to falls, impact with workstation, or blows from unsecured TASAR equipment	
003	Personal injury due to experimental system rack breaking loose and impacting crew personnel	
004	Personal injury due to fire originating from Workstation, TASAR equipment, or Personal Electronic Devices (PED).	
005	CFIT due to crew distraction, workload, or Hazardously Misleading TASAR information which, if followed, could lead to a compromise in terrain clearance	
006	Loss of Separation due to crew distraction, workload, or Hazardously Misleading TASAR information which, if followed, could lead to compromised aircraft separation	
007	Personal Injury resulting from adverse Weather Encounter due to crew distraction, workload, or hazardously misleading TASAR information	
008	Personal Injury resulting from inability to execute emergency egress from the aircraft on the ground due to obstruction caused by workstation AND/OR loose TASAR hardware and cables	
009	Personal Injury due to Cabin Depressurization. Loss of cabin airtight integrity due to failure of hardware related to the TASAR installation	
010	Compromise or loss of normal aircraft system operation because TASAR systems interfere electrically or electromagnetically with existing aircraft systems	
CONTROLS / CORRECTIVE ACTIONS TO BE BRIEFED		
Flight Conduct	1. The Pilot-in-Command (PIC) / Safety Pilot will not participate in the TASAR evaluation and will monitor autopilot and flight envelope at all times and will have a primary responsibility of maintaining ATC coordination, weather avoidance, and aircraft separation. 2. Operations will be conducted in the heart of the aircraft's flight envelope (10,000' – FL300), within approximately 20 KIAS of the aircraft's maneuvering speed (Va). 3. The Hard-Deck for TASAR operations will be 10,000ft or the MEA, whichever is higher, so terrain clearance will be assured for all TASAR operations. 4. All flight-testing will be conducted in an Instrument Flight Rules (IFR) environment, with normal ATC separation standards. 5. ATC clearance will be obtained prior to any non-emergency (e.g. TCAS RA or EGPWS escape) course or altitude modifications. 6. All crewmembers will be briefed on the importance of lookout, see-and-avoid, and the use of the clock system for locating targets. 7. Traffic conflicts and TCAS Traffic Advisories or RAs will be automatic cause for "knock-it-off" for all test points. 8. Unexpected adverse weather encounters, EGPWS cautions and warnings, and TCAS Resolution Advisories will be automatic cause for "knock-it-off" for all TASAR test points. 9. The PIC will call "knock-it-off" at any time if there is concern about the envelope being exceeded.	
Cabin Safety		
Cabin EPS		
10. All occupants will remain seated with safety belts secured, unless the PIC approves deviations from this requirement using a challenge and response protocol, considering applicable operational factors (turbulence, anticipated maneuvering, etc.). 11. The PIC will advise the crew of any pending maneuvers or anticipated turbulence encounters. 12. Movement about the cabin and seat-changes will be kept to a practical minimum, and will only be performed in smooth air. 13. EFBs and other loose equipment will be stowed when not in use, and for takeoff, landing, and critical flight phases (generally 10,000' MSL and below).		
14. The aircraft is equipped with a full fire fighting kit, including a firefighter's smoke hood with built-in oxygen and a portable Halon™ extinguisher. 15. AdvAero's Flight test Operations Manual FTOM requires a designated fire-fighter crewmember, and smoke and fire procedures are required to be briefed prior to each flight. 16. The flight-crew are provided with state-of-art 2-second single-hand-donning oxygen masks and all cabin personnel are provided with drop-down oxygen masks that automatically activate at 14,250 ± 250 ft. cabin altitude.		

Figure 17. TAP risk assessment and safety briefing.



RESIDUAL RISK (circled)				
FAILURE CONDITION FAILURE PROBABILITY	MINOR	MAJOR	HAZARDOUS	CATASTROPHIC
Probable	LOW	MEDIUM	HIGH	HIGH
Improbable-Remote	LOW	LOW	MEDIUM	HIGH
Extremely Remote	LOW	LOW	LOW	MEDIUM
Extremely Improbable	LOW	LOW	LOW	

	BRIEFING ELEMENTS	STATUS
1.	Roles and Responsibilities: SAFETY PILOT / PIC: FINAL AUTHORITY over safety of flight, positive aircraft control, adherence to regs. and limits. TEST DIRECTOR: optimizes flow and completion of test points, coordinates crew to achieve test objectives. DATA ENGINEER: collection of data in accordance with Test Director's requirements. FIRE CHIEF: in charge of firex and smoke hood. Distributes smoke goggles to pilots. Performs cabin fire drill.	N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
2.	Aircraft Identification and Requirements (incl. Flight Permit and any restrictions, especially re. autopilot usage) C-GJMM, Standard C of A, OpSpec #056 (NAFTA approval for flight-test operations by C-GJMM in U.S. Airspace) Issued March 1, 2013, valid until Mar 1, 2014	N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
3.	Flight Envelope / Configurations / Weight & Balance / Limits Normal P180 Flight envelope. 10,000 MSL TAP floor. Approx. Va at cruise for TAP operation.	N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
4.	Aircraft Safety Brief and Personal Equipment Exits, evacuation, O2 masks, life jackets, brace positions, survival and first aid kits, fire extinguisher and smoke hood, signals. Gravol, airsickness bags, "potty" procedures and access.	N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
5.	Cockpit Brief Safety harness, O2 masks, ICS /radio selection and volume, EFIS, ELT operation, emergency speeds and configurations.	N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
6.	Test Point Conduct and Abort Procedures "Abort, Abort" (except during take-off roll). P1 recovers to level flight or escape manoeuvre, as required.	N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
7.	Radio procedures Sterile cockpit below 10,000 ft. Minimize intercom usage. Brief Intercom silence hand-signal.	N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
8.	Traffic procedures Use of clock reference, high/low/threat/no threat. Pilot subjects can take control to avoid traffic in extreme circumstances, except during take-off and landing.	N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
9.	Data/Photo/Video Requirements In accordance with AdvAero NNL12AA06C TASAR Flight Trial Data Collection Plan dated Nov 8, 2013, or later edition.	N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
10.	Weather Minima and Flight Rules Standard IFR minima apply.	N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
11.	ATC Coordination, special airspace requirements Standard TAP Flight Plans on file with ATC and ATCC.	N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
12.	Fuel Requirements and Bingo fuel Standard IFR reserves, including 45 min. reserve after completing approach at alternate airport.	N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
13.		N/A <input type="checkbox"/> Briefed <input type="checkbox"/>
14.		N/A <input type="checkbox"/> Briefed <input type="checkbox"/>

MISSION BRIEFING AND RISK ACKNOWLEDGEMENT (PRINT AND SIGN)		DATE:
SAFETY PILOT PIC:	JOHN MARIS	PARTICIPANT PILOT:
TEST DIRECTOR:	MARK HAYNES	AIRCRAFT ENGINEER:
SOFTWARE ENGINEER:		NASA MONITOR:
OTHER:		OTHER:

Figure 18. TAP safety briefing (cont.)

12 REFERENCES

- ARINC. (2012). *834-3 aircraft data interface function (ADIE)*. (No. 828-3). Annapolis MD: ARINC Incorporated.
- Ballin, M., Sharma, V., Vivona, R., Johnson, E., & Ramiscal, E. (2002). A flight deck decision support tool for autonomous airborne operations. *2002 AIAA Conference on Guidance, Navigation, and Control, Monterey, CA*.
- Blanchard, B. S. (2008). *Systems engineering management* (4th ed.) Hoboken, NJ: John Wiley & Sons, Inc.
- Federal Aviation Administration (2012). *Guidelines for the certification, airworthiness, and operational use of portable electronic flight bags*. (Advisory Circular No. AC 120-76B). Washington, DC: AFS-400. (Electronic Flight Bag (EFB))
- Henderson, J. (2012). *Initial analysis of operational use cases and methodologies*. (No. NNL12AA06C). NASA.
- Henderson, J. (2013). *Traffic aware strategic aircrew requests (TASAR) concept of operations*. (No. CR-2013-218001). NASA.
- Maris, J. (2011). *Flight test operations manual (FTOM), revision 1*. (No. MVT-SFTSMS-02). Quebec, Canada: Marinvent Corporation.
- NASA. (2010). *NASA Langley procedural requirements protection of human research subjects*. (No. LPR 7100.10). NASA.
- NASA. (2013). Air traffic operations lab. Retrieved September 19, 2013, from <http://www.nasa.gov/centers/langley/multimedia/iotw-atol.html#.UjuiwRZa5SY>
- Roscoe, A., and Ellis, G., "A Subjective Rating Scale for Assessing Pilot Workload in Flight: A Decade of Practical Use," Royal Aerospace Establishment, ADA227864, Farnborough, U.K., 1990.
- RTCA SC-135. (2010). *Environmental conditions and test procedures for airborne equipment*. (No. RTCA/DO-160G). Washington, D.C.: RTCA, Inc.
- RTCA SC-205. (2011). *DO-178C software consideration in airborne systems and equipment certification*. Washington, D.C.: RTCA, Inc.
- SAE Aerospace S-18, & WG-63. (2010). *ARP 4754. Guidelines for development of civil aircraft and systems*. (Rev. A) SAE International.

TASAR flight test operations and safety report. (V 1.1, Mar 6, 2013). (No. NNL12AA06C DEL 19). Langley, VA: Advanced Aerospace Solutions, LLC.

TASAR flight trial approval requirements. (Rev 2.0, Feb 21, 2013). (No. NNL12AA06C DEL 7). Langley, VA: Advanced Aerospace Solutions, LLC.

TASAR flight trial test plan. (V1.1 May 31, 2013). (No. NNL12AA06C FTP). Langley, VA: Advanced Aerospace Solutions, LLC.

TASAR flight-trial hazard analysis. (V 2.0, Feb 13, 2013). (No. NNL12AA06C DEL 12). Langley, VA: Advanced Aerospace Solutions, LLC.

Vivona, R., Karr, D., & Roscoe, D. (2013). Pattern-based genetic algorithm for airborne conflict resolution. *2006 AIAA Conference on Guidance, Navigation, and Control, Keystone, CO*.

APPENDIX 1 AW&ST Article

Aviation Week and Space Technology Report on TAP, December 2, 2013

Soft Savings

NASA software helps pilots save time and money

John Croft **Newport News, Va.**

By mid-2014, pilots flying for at least one U.S. carrier could be able to save passengers time and their employer money with the push of a touchscreen and a verbal request to air traffic control during the cruise portion of a flight.

The capabilities are part of the NASA Langley Research Center's Traffic Aware Planner (TAP), an application that runs on electronic flight bags (EFB) in the cockpit. NASA flight-tested the system for the first time on an Advanced Aerospace Solutions Piaggio PJ80 avionics testbed for two weeks in November, generating input from a consultant pilot and eight airline pilots who evaluated the application.

Preliminary results of the flight test were positive, giving a boost to agreements in the works for airline deployment. David Wing, Traffic Aware Strategic Aircravt Requests (Tasar) principal investigator with NASA's

Pilots use the touchscreen on NASA's TAP application on an EFB to optimize routes for time and fuel savings.

Langley Research Center, says Virgin America is interested in using the software, as is a mainline carrier, assuming the application can be ported over to the iPad.

Paul Harrison, flight technical manager for Virgin America and one of the volunteer pilots to fly in the Piaggio, says TAP could be one of the first applications to run on newly installed class 3 EFBs in the airline's 53 Airbus A319 and A320 aircraft next year, albeit initially without the automatic dependent surveillance broadcast (ADS-B) "in" traffic feature. "Our draw to it is for fuel savings," says Harrison. "We do a lot of transcontinental flights, and the longer the flight, the more the savings."

Along with ADS-B "in," TAP uses broadband input for wind, airspace and weather information to help pilots optimize horizontal and vertical routing based on benefits to fuel burn, time en route, or a combination of the two. Behind the application is more than a decade of NASA research into self-separation, and more recently, a push from the Office of Management and Budget to develop tools that drive interest in voluntary equipage for ADS-B, says Wing.

Powering the application is a pattern-based genetic algorithm augmented by pilot-selected route optimization criteria that computes 500-800 trajectory alternatives waypoints every minute. Pilots can also use a manual mode to check for fuel or time savings at alternate altitudes or routing, with a maximum of two off-route waypoints, a number selected to limit air traffic controllers' workload.

TAP uses ADS-B data to determine if there are traffic conflicts with potential re-routes, a check that increases the likelihood that controllers might approve the request. The

Piaggio is equipped with an ACSS TCAS 3000 ADS-B unit and Inmarsat broadband, which is used to bring in wind values and information about special use airspace and weather disruptions. The system is meant to be used above 10,000 ft. so as not to interfere with high-workload portions of a flight.

"It's a non-safety-critical app," says NASA's Wing. "We're not changing roles of pilots and controllers. Pilots can already ask for a trajectory change. Controllers assess the request for safety, and approve or deny it."

Wing says pilots on most of the 2.5-hr. test flights were approved for one or more route changes based on TAP guidance. Pilots used one of three routes for the test flight, each with differing air traffic control or airspace complexities. Wing says the flight test was not meant to directly measure fuel and time savings, given that routes were "round-robin" and software did not include a performance model for the Piaggio. Rather, the test was meant to determine how TAP performed with on-board and external information, to ob-



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serve how the pilots interacted with the system and to generate change requests to air traffic control. "In my view, we accomplished this objective," says Wing.

An earlier study conducted by NASA subcontractor Engility Corp. determined that network carriers could save as much as 4.2 min. per flight by optimizing for time, or as much as 575 lb. of Jet A by optimizing on fuel burn. For a low-cost carrier, the savings are somewhat smaller—a maximum of 2.9 min. or 406 lb. of fuel saved, respectively. The numbers appear relatively small in isolation, but could be significant if aggregated across a carrier's fleet. The analysis considered 510 flights between July 11-20, 2012, flying between 12 U.S. city-pairs.

Engility also developed the TAP software and conducted the flight trials with its partner, Advanced Aerospace, the owner of the Piaggio. NASA also contracted with Rockwell Collins to assess implementation requirements in terms of certification approval for the application (their conclusion: "low certification approval threshold") as well as to conduct human-in-the-loop simulations with 12 airline pilots last summer. Those simulations, using a Boeing 777-200LR simulator at the University of Iowa's Operator Performance Laboratory, found that TAP has a "negligible effect on pilot workload" and that situational awareness was not degraded. ☀

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NASA's Traffic Aware Planner (TAP) is a cockpit decision support tool that provides aircrew with vertical and lateral flight-path optimizations with the intent of achieving significant fuel and time savings, while automatically avoiding traffic, weather, and restricted airspace conflicts. A key step towards the maturation and deployment of TAP concerned its operational evaluation in a representative flight environment. This Systems Engineering Management Plan (SEMP) addresses the test-vehicle design, systems integration, and flight-test planning for the first TAP operational flight evaluations, which were successfully completed in November 2013. The trial outcomes are documented in the Traffic Aware Planner (TAP) flight evaluation paper presented at the 14th AIAA Aviation Technology, Integration, and Operations Conference, Atlanta, GA. (AIAA-2014-2166, Maris, J. M., Haynes, M. A., Wing, D. J., Burke, K. A., Henderson, J., & Woods, S. E., 2014).					
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